1.0 INTRODUCTION

TABLE OF CONTENTS

HIGHLIGHTS

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1.0 INTRODUCTION

1.1 PURPOSE AND CONTENT

This document provides technical and policy guidance for project managers and management teams making risk management decisions for contaminated sediment sites. It is primarily intended for project managers considering remedial response actions or non-time-critical removal actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or more commonly known as "Superfund," although technical aspects of the guidance are also intended to assist project managers addressing sediment contamination under the Resource Conservation and Recovery Act (RCRA). Many aspects of this guidance will also be useful to other governmental organizations and potentially responsible parties (PRPs) that are conducting a sediment cleanup under environmental statutes, such as the Clean Water Act (CWA) or the Water Resource Development Act (WRDA).

Contaminated sediment is addressed in this guidance in a wide variety of aquatic environments, including rivers, streams, wetlands, ponds, lakes, reservoirs, harbors, estuaries, bays, intertidal zones, and coastal ocean areas. Sediment in wastewater lagoons, detention/sedimentation ponds, on-site tanks, on-site storage/containment facilities, or roadside ditches is not addressed. Although flood plain soils and upland source materials are important aspects of sediment sites, existing guidance [e.g., the U.S. Environmental Protection Agency's (EPA's) *Soil Screening Guidance* (U.S. EPA 1996a)] makes inclusion of these aspects less critical for new guidance. This guidance addresses both in-situ and ex-situ cleanup methods for sediment, including monitored natural recovery (MNR), in-situ capping, and dredging and excavation.

Following this introductory chapter, the guidance presents sediment-specific considerations during remedial investigations [(RI), see Chapter 2] and feasibility studies [(FS), see Chapter 3); evaluation of the three major cleanup methods for sediment (see Chapter 4, Monitored Natural Recovery, Chapter 5, In-Situ Capping, and Chapter 6, Dredging and Excavation); selection of sediment remedies (see Chapter 7); and sediment site monitoring (see Chapter 8). Although some issues concerning site characterization and risk are discussed early in the guidance, the emphasis of the guidance is on evaluating cleanup methods (i.e., the FS stage of the Superfund process).

1.2 CONTAMINATED SEDIMENT

For the purposes of this guidance, contaminated sediment is soil, sand, or other mineral or organic matter that accumulates on the bottom of a waterbody and contain toxic or hazardous materials that may adversely affect human health or the environment. It may wash from land, be deposited from air, erode from aquatic banks or beds, or form from underwater breakdown or buildup of minerals (U.S. EPA 1998a). Contaminated sediment may be present in wetlands, streams, rivers, lakes, reservoirs, harbors, along ocean margins, or in other waterbodies. In this guidance, "waterbody" generally includes all of these environments.

Examples of primary and secondary sources of contaminants in sediment are included in Highlight 1-1.

Highlight 1-1: Potential Sources of Contaminants in Sediment

- Direct pipeline discharges into a waterbody from industrial facilities, waste water treatment plants, storm water, or combined sewer overflows
- Chemical spills into a waterbody or wetland
- Surface runoff or erosion of flood plain soil from contaminated sources on land, such as spills, waste dumps and chemical storage facilities, and agricultural or urban areas
- Air emissions from power plants, incinerators, pesticide applications, or other sources, that may be transferred to a waterbody or wetland through precipitation, runoff, or direct deposition
- Up welling or seepage of contaminated ground water or non-aqueous phase liquids (NAPL) into a waterbody or wetland

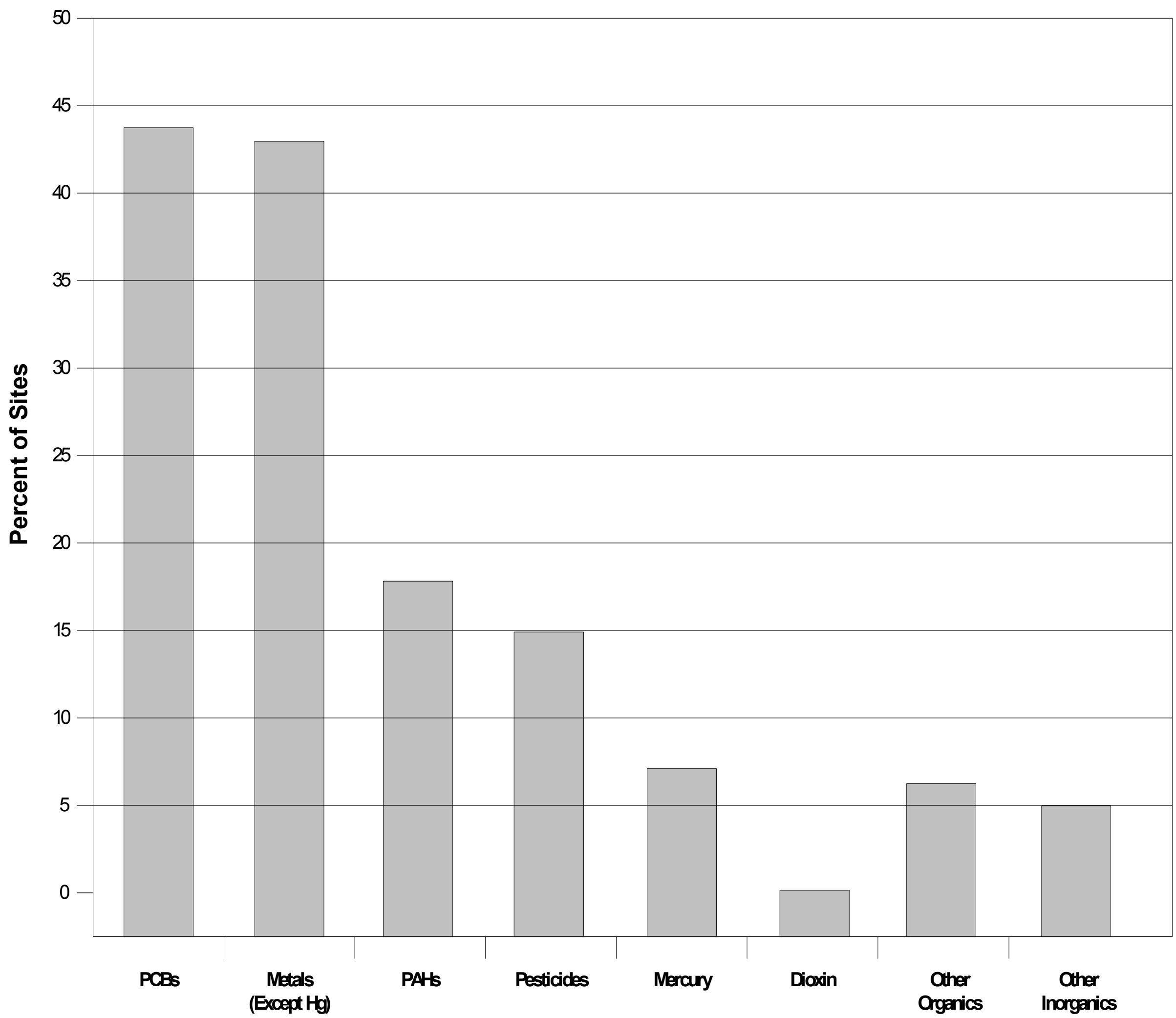
Organic contaminants in sediment typically adsorb to sediment particles and exist in the pore water between sediment particles. Metals also adsorb to sediment and may bind to sulfides in the sediment. The relative proportion of contaminants between sediment and pore water depends on the type of contaminant and the physical and chemical properties of the sediment and water.

Many contaminants persist for years or decades because the contaminant either does not degrade or degrades very slowly in the aquatic environment. Some bottom-dwelling organisms ingest contaminated sediment, and in shallow water environments, humans may also come into contact with contaminated sediment. Contaminants sorbed to sediment normally develop an equilibrium with the dissolved fraction in the pore water. Also, contaminants may dissolve back into the water column, to be taken up by fish and other aquatic organisms. Some contaminants, such as most metals, are primarily hazardous because of direct toxicity. Others, called persistent bioaccumulative toxics [(PBTs), e.g., polychlorinated biphenyls (PCBs), pesticides, and methyl mercury], are of concern because they may bioaccumulate, or magnify in concentration as they are passed up the food chain. Fish may become highly contaminated and endanger humans and wildlife that eat fish. Women of childbearing age, young children, people that derive much of their dietary protein from fish and shellfish, and people with impaired immune systems may be especially at risk.

In 2001, the EPA released for comment a draft report, *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States* (U.S. EPA 2001a). This report identifies locations where sediment contamination could be associated with probable or possible adverse effects to aquatic life and/or human health; these locations are in all regions of the country (U.S. EPA 2001a). The EPA is working on completing this document and expects to release in final form in 2003. States have issued more than 2,618 advisories limiting consumption of fish and wildlife, in large part due to sediment contamination (U.S. EPA 2002b). In addition, contaminated sediment has significantly impaired the navigational and recreational uses of rivers and harbors in the U.S. Navigational dredging is not currently being performed in many harbors and waterways because of the concern for impacts of dredging on water quality, liability to those doing the dredging, and disposal options for the contaminated dredged material [(National Research Council) NRC 1997 and 2001].

As of 2001, the Superfund program decided to take an action to clean up sediment at approximately 140 sites (U.S. EPA 2001a). The remedies for 66 sites are large enough that they are being tracked at the national level. These sites include a wide variety of contaminants, as presented in Highlight 1-2.

Highlight 1-2: Major Contaminants at Superfund Sediment Sites (Remedy Selected through 2001)



Many aspects of the cleanup process may be more complex at sediment sites versus sites with soil or ground water contamination alone. Some potential complicating factors are listed in Highlight 1-3. For these and other reasons as presented in this guidance a team of experts is frequently needed to advise the project manager.

Highlight 1-3: Why Are Sediment Sites a Unique Challenge?
• Sediment sites may have a large number of sources, some of which can be difficult to control
• The sediment environment is usually dynamic, and understanding the effect of natural and man-made events on sediment stability and contaminant transport can be difficult
• Cleanup work in an aquatic environment is frequently difficult from an engineering perspective and more costly than other media
• Contamination is often diffuse and the sites large and diverse (e.g., mixed use, numerous property owners)
• Many sediment sites contain ecologically valuable resources or legislatively protected environments
• For large sites, a number of communities with differing views and opinions may be affected
• There may be significant natural resource damages at interest in sediment sites

1.3 RISK MANAGEMENT PRINCIPLES AND METHODS

OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a), presents eleven risk management principles that will help project managers make scientifically sound and nationally consistent risk management decisions at contaminated sediment sites. Project managers should carefully consider these principles when planning and conducting site investigations, involving the affected parties, and selecting and implementing a response. While the directive applies to sediment sites addressed under CERCLA or RCRA, its implementation at particular sites should be tailored to the size and complexity of the site, to the magnitude of site risks, and to the type of action contemplated. The principles should be applied within the framework of the EPA's existing statutory and regulatory requirements, such as the National Oil and Hazardous Substances Pollution Contingency Plan's (NCP's) nine criteria in NCP §300.430(c). The eleven principles are listed in Highlight 1-4 and are incorporated throughout this guidance (see Appendix A for a complete version of the directive).

1.3.1 Cleanup Methods

Highlight 1-5 lists the major cleanup methods available for managing risks from contaminated sediment. Frequently, a final sediment remedy combines more than one type of method. In addition to these methods, many sediment remedies include the use of institutional controls, such as waterway or land use restrictions, and fish consumption advisories to limit exposures to contaminants. Institutional controls are discussed further in Chapter 3, Feasibility Study Considerations.

Highlight 1-4: Risk Management Principles for Contaminated Sediment Sites

- Control sources early
- Involve the community early and often
- Coordinate with states, local governments, tribes, and natural resource trustees
- Develop and refine a conceptual site model that considers sediment stability
- Use an iterative approach in a risk-based framework
- Carefully evaluate the assumptions and uncertainties associated with site characterization data and site models
- Select site-specific, project-specific, and sediment-specific risk management approaches that will achieve risk-based goals
- Ensure that sediment cleanup levels are clearly tied to risk management goals
- Maximize the effectiveness of institutional controls and recognize their limitations
- Design remedies to minimize short-term risks while achieving long-term protection
- Monitor during and after sediment remediation to assess and document remedy effectiveness

Source: U.S. EPA 2002a

Highlight 1-5: Potential Cleanup Methods for Contaminated Sediment

In-situ Methods	Ex-situ Methods
In-Situ Capping: • Single-layer granular caps • Multi-layer granular caps • Combination granular/geotextile caps	Dredging: • Hydraulic • Mechanical • Combination • Treatment and/or disposal of dredged material
Monitored Natural Recovery: • Physical processes • Chemical processes • Biological processes	Excavation: • Water diversion/dewatering • Treatment and/or disposal of excavated material
In-situ Treatment (currently experimental only): • Reactive caps • Additives/enhanced biodegradation	

1.3.2 Urban Revitalization and Reuse

Revitalization of urban areas and returning land and waterbodies to productive use have become increasingly important to the Superfund program in recent years. Sediment sites may present opportunities to incorporate these concepts into remedy selection, remedial design, and into other phases of the risk management process. At sediment sites in urban areas, project managers should look for opportunities to help meet the goals of local governments and other entities to revitalize use of waterfront property, harbors, and other waterbodies. This may involve identifying potential partners such as land owners, elected officials, local land and water planning and development agencies, and reviewing local land use plans. It may lead to opportunities to tailor remedies to conform with the wishes of local stakeholders, land owners, and land use planners. For example, it may be possible to locate disposal structures or rail lines in areas that maximize future reuse. Beneficial reuse of dredged material also may present an opportunity for urban revitalization.

1.4 DECISION-MAKING PROCESS

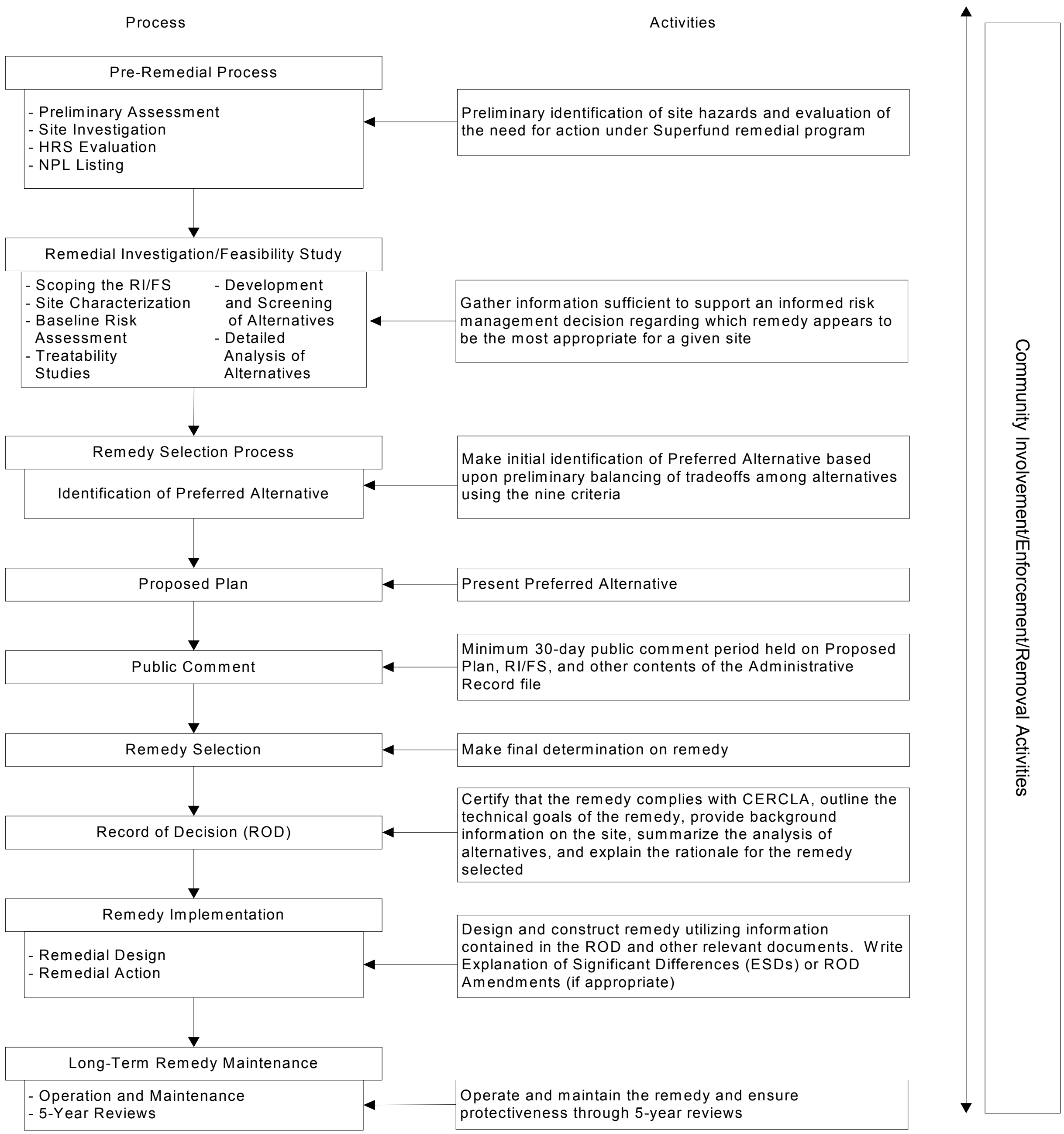
The Superfund remedial response process is shown in Highlight 1-6, taken from *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents*, also referred to as the "ROD Guidance" (U.S. EPA 1999a). See the ROD Guidance for detailed descriptions of each stage of the process. This process is the decision-making framework that project managers should use for remedial actions under CERCLA. The RCRA remedial process is laid out in the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR), 61 FR 19447].

In the report *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001), the NRC recommended the use of the iterative decision-making approach shown in Highlight 1-7. This approach fits within the context of EPA's existing remedial process (Highlight 1-6) and serves to remind project managers of the usefulness of iteration and the importance of public involvement throughout the decision-making process. However, as the NRC (2001) noted: "The use of the NRC approach should not be used to delay a decision at a site if sufficient information is available to make an informed decision. Particularly in situations where there are immediate risks to human health or the ecosystem, waiting until more information is gathered may result in more harm than making a preliminary decision in the absence of a complete set of information."

1.5 TRUSTEE, STATE, AND TRIBAL INVOLVEMENT

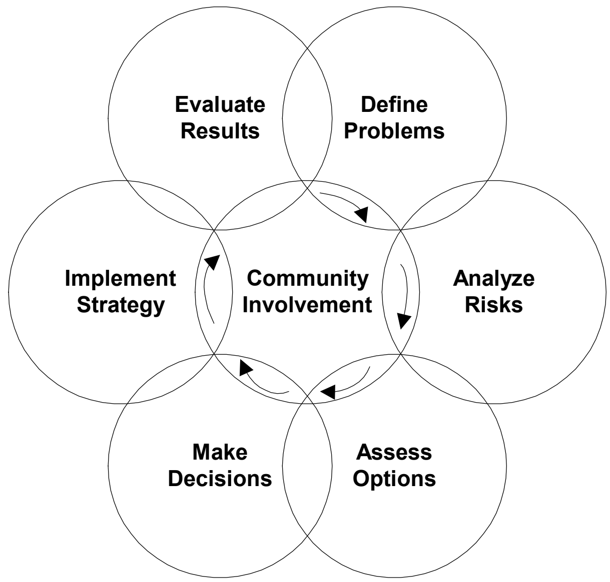
Where there are natural resource damages associated with sediment sites, coordination between the remedial and trusteeship roles at the federal, tribal, and state levels is especially important. Several different federal, state, or tribal natural resource trustees may have an interest in decisions concerning contaminated sediment sites and should be involved throughout the investigation and remedy selection process. The EPA is required to promptly notify natural resource trustees whenever a release of hazardous materials, contaminants, or pollutants may injure natural resources (CERCLA §104 (b)(2)). Trustees may include federal natural resource trustee agencies, such as the U.S. Department of the Interior (DOI), the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Agriculture (USDA) Forest Service, U.S. Department of Defense (DoD), or U.S. Department of Energy (DOE). State agencies and federally-recognized tribes may also be natural resource trustees. Where NOAA is the natural resource trustee, project managers should contact the Coastal Resource

Highlight 1-6: Superfund Remedial Response Process



Source: U.S. EPA 1999a

Highlight 1-7: National Research Council - Recommended Framework for Risk Management



Source: Adapted from NRC 2001

Coordinators (CRCs) who are assigned to each EPA Region (except Regions 7 and 8, where there are no NOAA trust resources). These CRCs are also designated natural resource trustee representatives for marine resources, including migratory fish.

Interests and data needs of the trustees and the EPA may be similar. Project managers should consult trustees early in the RI/FS process regarding potential contaminant migration pathways, ecological receptors, and characteristics of the waterbody and watershed. Sharing information early with federal, tribal, and state trustees (rather than bringing them in later in the process) often leads to better protection of human health and the environment and reduces the time needed to negotiate liability settlements. Information on coordinating with trustees is found in *EPA's ECO Update: The Role of Natural Resource Trustees in the Superfund Process* (U.S. EPA 1992a), in OSWER Directive 9200.4-22A, *CERCLA Coordination with Natural Resource Trustees* (U.S. EPA 1997a), and in OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (U.S. EPA 1999b).

In addition to their role as natural resource trustees, state cleanup agencies and affected Indian tribes or nations have an important role as co-regulators and/or affected parties and as sources of essential information. States can be the lead agency at some sediment sites, or lead the cleanup of source areas or particular Operable Units within a site. States and tribes are frequently an indispensable source of historic and current information about waterbody uses, fish consumption patterns, ecological habitat, other sources of contamination within a watershed, and other information useful in characterizing the site and selecting an appropriate remedy. Additional information on coordinating with states and tribes can be found in OSWER Directive 9375.3-03P, *The Plan to Enhance the Role of States and Tribes in the Superfund Program* (U.S. EPA 1998b), and OSWER Directive 9375.3-06P, *Enhancing State and Tribal Role Directive* (U.S. EPA 2001b), both available at http://www.epa.gov/superfund/states/strole/index.htm.

1.6 COMMUNITY INVOLVEMENT

People who live, work, and play adjacent to waterbodies that contain contaminated sediment should receive accurate information about the safety of their activities, and be provided opportunities for involvement in the EPA's decision-making process for sediment cleanup. Both communication and outreach pose unique community involvement challenges at sediment sites. Sediment sites that span large areas may present barriers to communicating effectively with the different communities along the waterbody. Community members may have a wide variety of needs and wishes for current and future uses of the waterbody. Highlights 1-8 and 1-9 list some of the common community concerns about contaminated sediment and sediment cleanup methods. These lists are compiled from information provided by Superfund project managers and by the NRC (2001). Project managers should be aware of these potential concerns and others specific to their sites.

Highlight 1-8: Common Community Concerns about Impacts/Effects of Contaminated Sediment

- Human health impacts from eating fish/shellfish, wading, and swimming
- Ecological impacts on wildlife and aquatic species
- Loss of recreational, and subsistence fishing opportunities
- Loss of recreational swimming and boating opportunities
- Loss of traditional cultural practices by tribes and others
- Economic effects of loss of fisheries
- Economic effects on development, reduction in property values, or property transferability
- Economic effects on tourism
- Concern whether all contamination sources have been identified
- Increased costs of drinking water treatment, other effects on drinking water, and other water uses
- Loss or increased cost of commercial navigation

Highlight 1-9: Common Community Concerns about Adverse Impacts of Sediment Cleanup

Concerns about Monitored Natural Recovery	Concerns about In-Situ Capping	Concerns about Dredging and Excavation
• Long time-frame for recovery • Spreading of contamination due to flooding/other disturbance • Extended loss of resources and uses • Perception of "do nothing" remedy, doubts about effectiveness • Environmental justice and other community concerns with leaving waste in place • Property value/transferability concerns with leaving waste in place	• Increased truck or rail traffic • Loss of resource/ harvesting rights • Navigational limitations • Increased flooding • Disturbance of aquatic habitat • Cap material source issues • Loss of ship anchoring access • Access to buried utilities • Cap erosion or disruption • Contaminant migration through cap • Loss of privacy during construction • Recreation and tourism impacts • Environmental justice and other community concerns with disruption and leaving waste in place • Property value/transferability concerns with leaving waste in place	• Increased truck or rail traffic • Noise, emissions, and lights at treatment and disposal facilities • Siting of new disposal facilities • Loss of capacity at existing disposal facilities • Loss of privacy during construction • Infrastructure needs on adjacent land • Recreation and tourism impacts • Access to private property • Property values near dredging, treatment and disposal facilities • Disturbance of aquatic habitat • Environmental justice and other community concerns with disruption • Resuspension/spreading contamination

Existing community involvement and sediment guidance from the EPA and elsewhere offer some guidelines for involving the community in meeting these and other concerns, as identified in Highlight 1-10.

Highlight 1-10: Community Involvement Guidance and Advice

EPA Office of Solid Waste and Emergency Response on Community Involvement:

- *Early and Meaningful Community Involvement* (U.S. EPA 2001c)
- *Superfund Community Involvement Handbook and Toolkit* (U.S. EPA 2001d)
- *Community Advisory Group Toolkit for EPA Staff* (U.S. EPA 1997b)
- *The Model Plan for Public Participation*, National Environmental Justice Advisory Council (U.S. EPA 1996b)

RCRA Community Involvement Guidance:

- *RCRA Public Participation Manual* (http://www.epa.gov/epaoswer/hazwaste/permit/pubpart/manual.htm)
- *RCRA Expanded Public Participation Rule* (60 FR 63417-34)
- *RCRA Corrective Action Workshop Communication Tools* (http://www.epa.gov/epaoswer/hazwaste/ca/resource/guidance/pubinvol/comtools.htm)

Office of Water on Communication of Fish Consumption Risks and Surveys:

- *Guidance for Conducting Fish and Wildlife Consumption Surveys* (U.S. EPA 1998c)
- *National Conference on Risk Communication and National Forum on Contaminants in Fish* (Chicago 2001 conference proceedings available at http://www.epa.gov/ost/fish)

National Research Council:

- *A Risk-Management Strategy for PCB-Contaminated Sediments, Chapter 4, Community Involvement* (NRC 2001)

Considering existing EPA guidance, and advice from the NRC and others, the three points below highlight some of the most critical aspects of community involvement at sediment sites.

1: Involve the Community Early and Often

One of EPA's eleven principles for managing risk of contaminated sediment is to involve the community early and often. The mission of the Superfund and RCRA community involvement programs is to advocate and strengthen early and meaningful community participation during Superfund cleanups. Planning for community involvement at contaminated sediment sites should begin as early as the site discovery and site assessment phase and continue throughout the entire Superfund process. As noted by the NRC (2001): "Community involvement will be more effective and more satisfactory to the community if the community is able to participate in or directly contribute to the decision-making process. Passive feedback about decisions already made by others is not what is referred to as community or stakeholder involvement." Early community involvement enables EPA to learn what community members think are important exposure pathways and to assess societal and cultural impacts of the contamination and of potential response options. Available materials about community involvement in the risk assessment process include *A Community Guide to Superfund Risk Assessment – What's it All about and How Can You Help?* (U.S. EPA 1999c). This guide and other Superfund community involvement materials are available at http://www.epa.gov/superfund/resources and guidance for RCRA corrective action programs at http://www.epa.gov/epaoswer/hazwaste/ca/guidance.htm. Although the regulators have the responsibility to make the final cleanup decision at CERCLA and RCRA sites, early and frequent community involvement helps the regulators understand differing views and allows the regulators to factor these views into their decision.

2: Build an Effective Working Relationship with the Community

Building partnerships with key community groups and interested parties is critical to implementing a successful community involvement program. Involving communities by fostering and maintaining relationships can lead to better site decisions and faster cleanups. Writing specifically about PCB-contaminated sites, but with application to all sediment sites, the NRC (2001) report recommended that: "Community involvement at PCB-contaminated sediment sites should include representatives of all those who are potentially at risk due to contamination, although special attention should be given to those most at risk."

Participants at EPA's 2001 *Forum on Managing Contaminated Sediments at Hazardous Waste Sites* (U.S. EPA 2001e) offered the following ideas, among others, for building effective working relationships with communities at sediment sites. Project managers should consider the following advice as they formulate their plans for community involvement:

- Create realistic expectations up front for both public involvement and sediment cleanup;
- Where possible, do not ask for extra meetings, instead, ask for time at existing community meetings;
- Use store-front on-site offices for public information when possible;
- Be aware of tribal cultural and historic sites, not all are registered or are on tribal land;
- Minimize jargon when speaking and writing for the public;
- Use independent facilitators for public meetings when needed;
- Include broad representation of the community;
- Look for areas where you can act on input from the community; and
- Encourage continuity of membership as much as possible.

A complete list of Forum presentation materials is available at http://www.epa.gov/superfund/new/sedforum.htm.

3: Provide the Community with the Resources They Need to Participate Effectively in the Decision-Making Process

Project managers should ensure that community members have access to the tools and information they need to participate throughout the cleanup process. Educational materials should be accessible, culturally sensitive, relevant, timely, and translated when necessary.

Contaminated sediment sites often involve difficult technical issues. It is especially important to give community members opportunities to gain the technical knowledge necessary to become informed participants. Project managers should provide technical information to communities in formats that are accessible and understandable. The EPA has a number of resources available to help make large volumes of complex data more easily understandable. These resources are often valuable communication tools not only with the community, but also within the EPA and between cooperating Agencies. An example includes the Region 5 Fully Integrated Environmental Location Decision Support (FIELDS) process. FIELDS began as an effort to more effectively solve contaminated sediment problems in and around the Great Lakes and is applied in other regions as well. Information about FIELDS is available at http://www.epa.gov/region5fields.

Information about Superfund community services is available at http://www.epa.gov/superfund/action/community/index.htm. This web site provides information on Community Advisory Groups (CAGs), EPA's Technical Assistance Grant (TAG) program, and the Technical Outreach Services for Communities (TOSC) program. The TOSC program uses university educational and technical resources to help community groups understand the technical issues involving hazardous waste sites in their communities. The Superfund statute provides for only one TAG per site. At very large sites with diverse community interests, communities may choose to form a coalition and apply for grant funding as one entity. The coalition would need to function as a nonprofit corporation for the purpose of participating in decision making at the site. Individual organizations may choose to appoint representatives to a steering committee that decides how TAG funds should be allocated, and defines the statement of work for the grant. The coalition group may hire a grant administrator to process reimbursement requests to the EPA and to ensure consistent management of the grant. In some cases, EPA regional office award officials may waive a group's $50,000 limit if site characteristics indicate additional funds are necessary due to the nature or volume of site-related information.

2.0 REMEDIAL INVESTIGATION CONSIDERATIONS

TABLE OF CONTENTS

HIGHLIGHTS

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2.0 REMEDIAL INVESTIGATION CONSIDERATIONS

Generally, the purpose of investigating contaminated sediment, as with other media, is to determine the nature and extent of contamination sufficient to assess risks and to evaluate potential cleanup methods. The remedial investigation (RI) process is described in the U.S. Environmental Protection Agency's (EPA) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, also referred to as the "RI/FS Guidance" (U.S. EPA 1988a). The remedial process in Resource Conservation and Recovery Act (RCRA) corrective action is best described in OSWER Directive 9902.3-2A, *RCRA Corrective Action Plan*, and the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR) 61 FR 19447]. This chapter supplements existing guidance by offering brief sediment-specific guidance about site characterization and other investigation issues unique to sediment. More detailed guidance concerning site characterization is beyond the scope of this document, but may be developed as needed in the future. One important aspect of the investigation process not addressed here is the performance of human health and ecological risk assessments. Project managers should use existing EPA risk guidance (U.S. EPA 1989, U.S. EPA 1997c, U.S. EPA 1999b) and consider additional guidance as it is developed.

2.1 SITE CHARACTERIZATION AND CONCEPTUAL SITE MODELS

The site characterization process for a contaminated sediment site should allow the project manager to accomplish the following goals:

- Identify and quantify the contaminants present in sediment, surface water, and biota;
- Understand the vertical and horizontal distribution of the contaminants within the sediment;
- Identify the sources of historical contamination and quantify any continuing sources;
- Understand the physical, chemical, and biological processes affecting the fate, transport, and bioavailability of sediment contaminants at the site;
- Identify the complete human and ecological exposure pathways for the contaminants;
- Identify current and potential human and ecological risks posed by the contaminants; and
- Provide a baseline of data that can be used to monitor remedy effectiveness.

The types of data the project manager should collect are determined mostly by information needed to conduct the risk assessments, document baseline condition prior to implementation of the remedy, evaluate potential remedies, and to design and implement the selected remedy. Data quality objectives (including the type and number of samples, as well as the desired quality of the data) should be coordinated with other agencies (e.g., trustee agencies, state health departments) that have similar data needs. Highlight 2-1 lists some general types of physical, chemical, and biological data that a project manager should consider collecting when characterizing a sediment site. At these sites, it is important to

Highlight 2-1: Example Site Characterization Data for Sediment Sites

Physical	Chemical	Biological
• Sediment mineralogy and particle size/distribution • In-situ porosity/bulk density • Bearing strength • Specific gravity • Salinity profile of sediment cores • Geometry/bathymetry of waterbody • Turbidity • Sediment deposition rate • Depth of mixing layer/ degree and depth of bioturbation • Geophysical surveys • Annual and event-driven hydrographs and current velocities • Tidal regime • Freeze/thaw cycle of water body	• Near-surface contaminant concentrations in sediment • Contaminant concentration profiles in sediment cores • Contaminant concentrations in biota • Total organic carbon (TOC) in sediment • Dissolved, suspended, and colloidal contaminant concentrations in water column • Simultaneously extracted metals (SEM) of sediment • Acid volatile sulfide (AVS) in sediment • Oxidation/reduction profile of sediment cores • pH profile in sediment cores • Carbon/nitrogen/ phosphorus ratio • Un-ionized ammonia	• Sediment toxicity • Presence/absence of indicator species • Benthic species abundance/diversity • Abundance/diversity of emergent and submerged vegetation • Reproduction rates of fish, birds, other biota • Pathological condition, such as presence of tumors • Other contaminant effects

understand how characteristics change with seasonal conditions, especially during high and low water flows or with fluctuating water temperatures. The relative importance of these types of data are dependent on the site.

The data needed to determine the nature and extent of contamination and the risks to human health and the environment should be collected during the RI. A site characterization should include sufficient data to document long-term post-remedial data trends in a statistically defensible manner. Additional sampling could be needed during remedial design to establish a baseline for a long-term monitoring program. Any measurement used in a long-term monitoring program such as contaminant concentration in fish tissue not collected during site characterization should be quantified prior to any remedial action so that temporal and spatial changes may be documented accurately. While sediment sites typically demand more types of data for effective characterization than other types of sites, the data acquisition process should not prevent early action when appropriate.

For sediment sites as for other types of sites, the conceptual site model is an important element needed for evaluating remedies. The initial conceptual site model provides the project manager with a simple understanding of the site based on available data early in the RI, including any historical data, prior to the gathering of new site data. Later, this conceptual model should be modified as additional sources, pathways, and contaminants are identified during site characterization. The state, tribal, and federal natural resource trustee agencies may have information about the ecosystem that is important in developing the conceptual site model and it is recommended that trustees have input at this stage of the site investigation. Information gaps may be discovered in development of the conceptual site model requiring collection of new data.

Typically, the essential elements of the conceptual site model are the sources of the contaminants of concern, contaminant transport pathways, exposure pathways, and receptors at various levels of the food chain. Project managers may find it useful to develop several conceptual site models which highlight different aspects of the site. Highlight 2-2, Highlight 2-3, and Highlight 2-4 present examples which focus on ecological and human health threats.

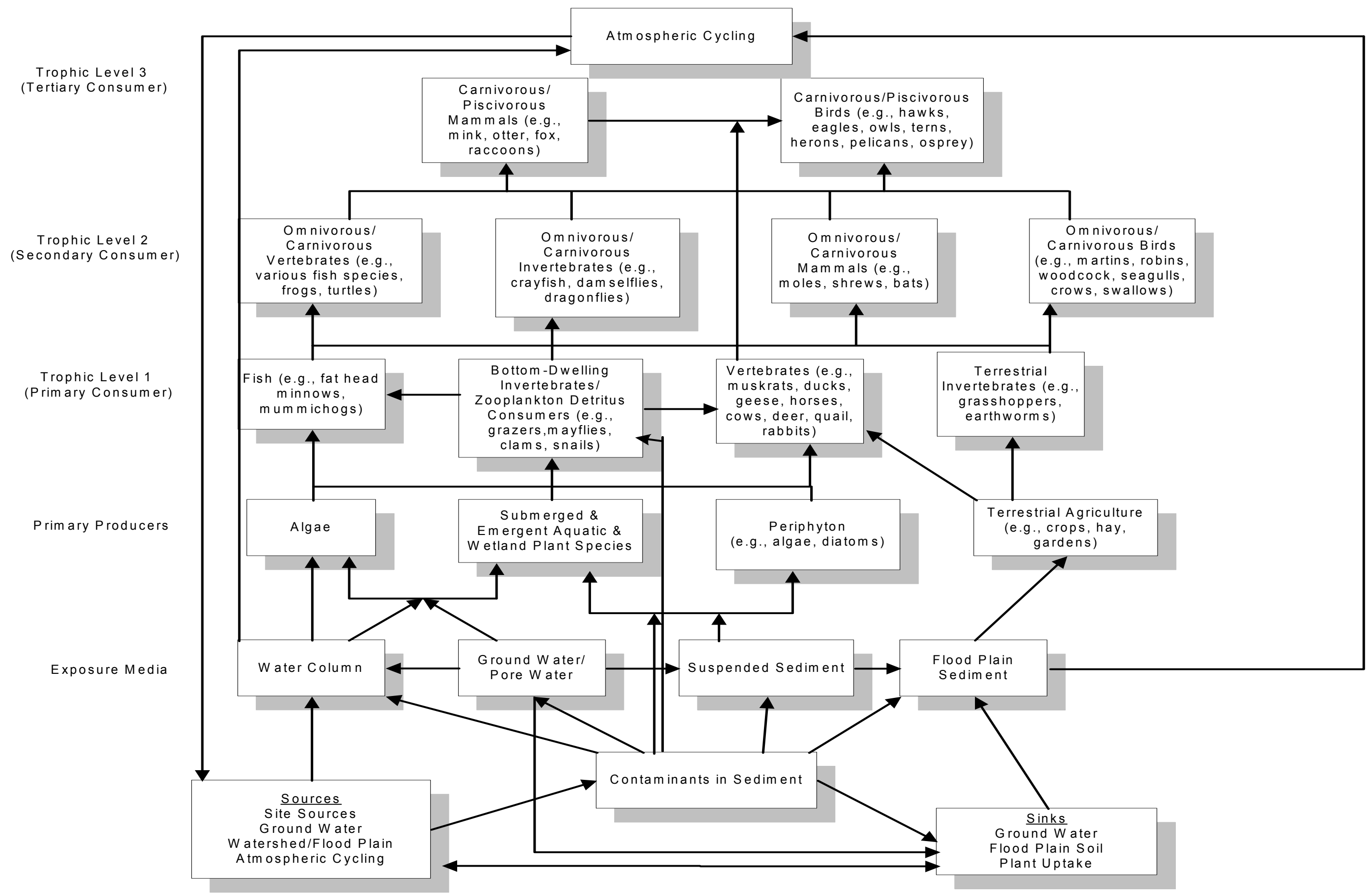
2.2 WATERSHED CONSIDERATIONS

A unique aspect of contaminated sediment sites is their relationship with the overall watershed in which they are located. Project managers should consider the role of the site in the watershed context, including other potential contaminant sources, key issues within the watershed, and current and reasonably anticipated or desired future uses of the waterbody and adjacent land.

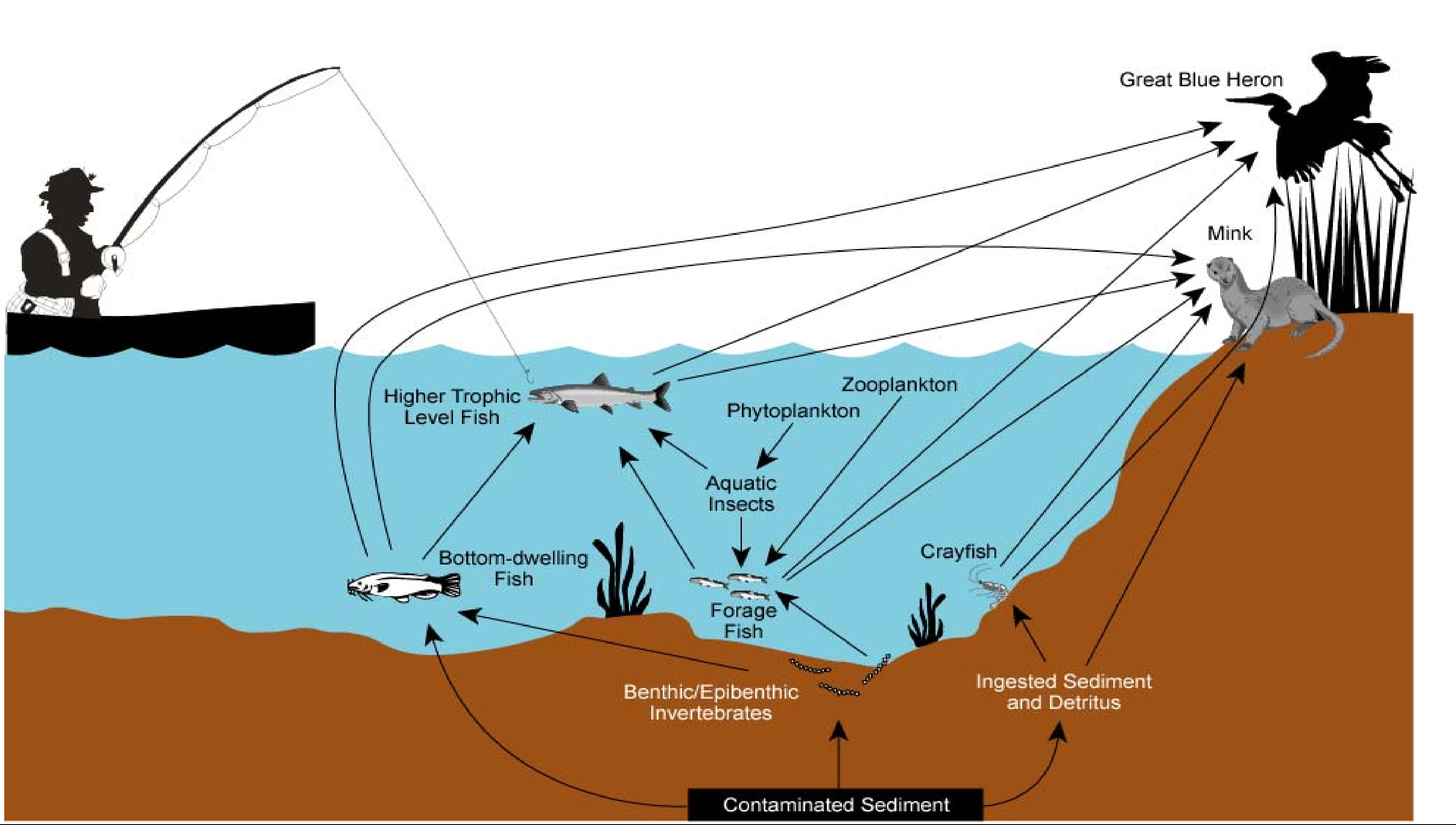
Within the watershed there are a spectrum of issues that the project manager may need to consider. Many contaminated sediment sites provide (or could provide) an important ecological environment for spawning, migration, or food production for fish, shellfish, birds, and other aquatic and land-based animals. One significant watershed issue is the protection of migratory fish. These are fish such as salmon, shad, and herring, that migrate as adults from marine waters up estuaries and rivers to streams and lakes, where they spawn. The juveniles spend varying lengths of time in freshwater, before migrating back to estuarine/marine waters. It is difficult to evaluate the impact of a particular contaminated sediment site on wide-ranging species that may encounter several sources of contamination along their migratory route. This is an important watershed consideration, as these fish populations may not show improvement if any link in their migratory route is missing, blocked, or toxic.

The size, topography, and land use of a watershed, among other factors, may affect characteristics of a waterbody, such as water quality, sedimentation rate, grain size and volume, seasonal changes in water volumes and current velocities, and the potential for ice formation. For example, wetland areas store flood waters and enable ground water recharge, thereby protecting downstream areas from increased flooding, whereas an agricultural or urbanized watershed may have increased erosion and greater flow during storm events. Watershed changes can result from natural events, such as wildfires, or from human activities such as road and dam construction/removal, impoundment releases, and urban/suburban development. When considering watershed characteristics, it is important to consider both current and future watershed conditions.

Highlight 2-2: Conceptual Site Model Focusing on Ecological Threats

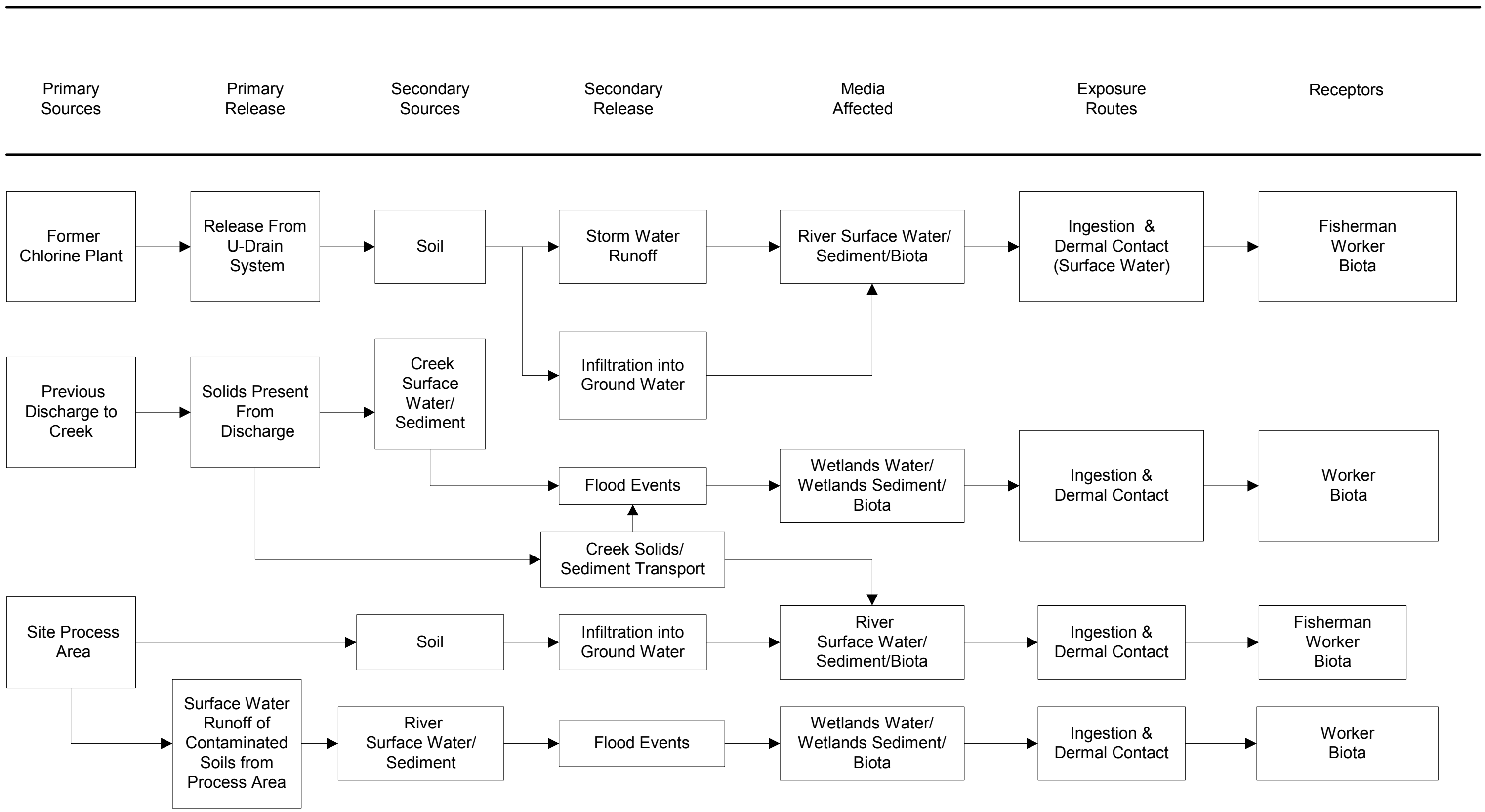


Highlight 2-3: Pictorial-Style Conceptual Site Model Focusing on Human and Ecological Threats



Source: Adapted from EPA Region 5, Sheboygan Harbor and River Site

Highlight 2-4: Conceptual Site Model Focusing on Human Health Threats



Waterbody uses may include commercial navigation, recreation, other commercial or industrial uses, recreational, subsistence or cultural fishing, and other, less easily categorized uses. Most waterbodies used for commercial navigation, such as for shipping channels, turning basins, and port areas, are periodically dredged to conform to the minimum depth for the area prescribed by Congress; such dredging is typically implemented by the U.S. Army Corps of Engineers (USACE). Other commercial or industrial uses of a site may include the presence of commercial fisheries or other resource harvesting, such as gravel pits, drinking water use, and industrial uses of water including cooling, washing, or waste disposal.

Recreational uses encompass a wide variety of activities including recreational fishing/shellfishing leading to ingestion of contaminated biota. These activities may involve direct human contact with contaminated sediment, for example, shallow waterbodies used for swimming, fishing, bird-watching adjacent to wetlands, or hunting. Activities may also include those with a lower probability of direct human contact with contaminated sediment, such as recreational boating.

Societal and cultural practices throughout the watershed should be considered in evaluating the risk associated with the contaminants at the site and during remedy evaluation. Refer to Chapter 1, section 1.6, Community Involvement, and Highlight 1-8 for a list of common community concerns at sediment sites. The National Research Council's (NRC) report, *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001), emphasizes that societal and cultural impacts should be considered when developing risk-management goals for contaminated sediment sites.

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) states that both current and future land uses should be evaluated in assessing risks posed by contaminants at a Superfund site, and that Superfund remedies should protect for reasonably anticipated future use. EPA has provided further guidance on how to evaluate future land use in the OSWER Directive 9355.7-04, *Land Use in the CERCLA Remedy Selection Process*, also referred to as the "Land Use Guidance" (U.S. EPA 1995a). This guidance promotes early discussions with local land use planning authorities, local officials, and the public regarding reasonably anticipated future uses of upland properties associated with an NPL site. This coordination should begin during the scoping phase of the RI/FS, and ongoing coordination is required to ensure that any changes in expectations are incorporated into the remedial process.

The Land Use Guidance provides tools to help the project manager plan for future land use in the watershed, including the fate of nearshore areas. However, there are additional factors the project manager should consider in anticipating future use for aquatic sites that are not specifically addressed in the Land Use Guidance. For example, future use of the site by ecological receptors may be a more important consideration for an aquatic Superfund or RCRA site as compared to an upland site. This could suggest the possibility of habitat restoration and subsequent increases in local wildlife populations. A remediated aquatic site, especially where habitat has been restored, attracts more recreational, subsistence, and cultural use, including fishing, swimming, and boating. Where applicable, the project manager should consider tribal treaty rights to collect fish or other aquatic resources. The project manager should also consider designated uses in the state's water quality standards, priorities established as a result of total maximum daily loads (TMDLs), or pollution reduction efforts under various Clean Water Act (CWA) programs in projecting future waterway uses. In ports and harbors, the project manager should consult future use master plans developed by port and harbor authorities for projections of future use. The USACE should also be contacted regarding future dredging of federally maintained channels.

There are likely to be more parties to consult about anticipated future use at aquatic sites than at upland sites. These parties include the community, environmental groups, natural resource trustees, Indian tribes, the local department of health, as well as local government, port and harbor authorities, and land use planning authorities. As with upland sites, consultation should start at the RI/FS scoping phase and continue throughout the life of the project. Different stakeholders often have divergent and conflicting ideas about future use at the site. Local residents and environmental groups may anticipate future habitat restoration and increased recreational and ecological use while local industrial landowners project increased shipping and industrial use. The NCP Preamble (55 FR 8710) states that, in the baseline risk assessment, more than one future use assumption is considered when decision makers wish to understand the implications of unexpected exposures. Especially where there is some uncertainty regarding the anticipated future uses, the project manager should compare the potential risks associated with several use scenarios.

Appropriate future use assumptions during the baseline risk assessment and the feasibility study allow the project manager to focus on the development of practicable and cost-effective remedial alternatives. In addition, coordination with stakeholders on land and waterway uses leads to opportunities to coordinate Superfund or RCRA remediation with local development or habitat restoration projects. For example, at some sites the EPA has worked with port authorities to combine Superfund or RCRA remedial dredging with dredging needed for navigation. Others have combined capping needed for Superfund or RCRA remediation with habitat restoration, allowing potentially responsible parties to settle natural resource damage claims in conjunction with the cleanup.

2.3 PHASED APPROACHES

At some sediment sites, a phased approach to remedy selection or remedy implementation may be the best or only practical option. For example, at sites where contaminant fate and transport processes are not well understood or all potential risks are not yet well characterized, it may be appropriate to control sources or take early or interim actions, followed by a period of monitoring before deciding on a final remedy. Phasing may also be useful where the effectiveness of source control is in doubt. By studying the effectiveness of source control prior to sediment cleanups, the risk of having to revisit re-contaminated areas is lessened. High remedy costs and/or the lack of available services and/or equipment can also lead to a decision to phase the cleanup.

Project managers are also encouraged to use an iterative approach, especially at complex sediment sites in order to provide additional certainty and information to support decisions. In general, this means testing of hypotheses and conclusions and reevaluating site assumptions as new information is gathered. For example, an iterative approach might include gathering and evaluating multiple data sets or pilot testing to determine the effectiveness of various remedial technologies at a site. The extent to which iteration is cost-effective is, of course, a site-specific decision. Using iteration to reduce uncertainty may be extremely cost-effective where it allows use of less costly alternatives; however, uncertainty in some areas is less critical.

2.3.1 Source Control

Identifying and controlling contaminant sources is an important consideration in any Superfund sediment cleanup. Source control is defined as those efforts that are taken to eliminate or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the waterbody under investigation. At some sediment sites, the original sources of the contamination have already been controlled, but subsequent sources such as contaminated flood plain soils, storm water discharges, and seeps of non-aqueous phase liquids may continue to introduce contamination to a site. At other sediment sites, some sources may be outside the boundaries of the Superfund or RCRA site and may best be handled under another authority, such as the CWA or state toxics program. These types of sites present an opportunity for partnering with private industry and other governmental entities to control sources on a watershed basis.

The identification of continuing sources and their potential to re-contaminate site sediment are essential parts of site characterization. When there are multiple sources, it is important to prioritize sources to determine the relative significance of continuing sources versus on-site sediment in terms of site risks in order to assess where to focus resources. To assist with that prioritization effort, project managers should consider developing a source control strategy or approach for the site as early as possible in the process of site characterization. The source control strategy should include requirements for documenting and tracking source control plans, source prioritization, completed source control actions, and effectiveness of source control measures. It is also useful to establish administratively defined milestones for source control that can be linked with sediment design and cleanup actions.

Generally, significant continuing sources should be controlled to the greatest extent possible before or concurrent with cleanup of sediment. Once source control is implemented, project managers should evaluate the effectiveness of the source control actions, and should refine and adjust levels of source control, as warranted. In most cases, before any sediment action is taken, project managers should consider the potential for re-contamination and factor that potential into the remedy selection process. If a site includes a source that could result in significant re-contamination, source control measures will likely be necessary as part of that response action. However, where EPA believes that sediment remediation may be a benefit to human health and/or the environment after considering the risks caused by an unaddressed or ongoing source, it may be appropriate for the Agency to select a response action for sediments prior to completing all source control actions.

Source control activities are often broad-ranging in scope. Source control may include application of regulatory mechanisms and remedial technologies to be implemented according to applicable or relevant and appropriate requirements (ARARs), including the application of technology-based and water quality-based National Pollutant Discharge and Elimination System (NPDES) permitting to achieve and maintain sediment cleanup levels. Source control actions may include the following:

- Elimination of the source;

- Development of a TMDL and pollutant load reductions of point and non-point sources;

- Implementation of best management practices (e.g., reducing chemical releases to a storm drain line);

- Treatment of sources (e.g., installing additional waste treatment systems prior to discharge); and

- Isolation or containment of sources (e.g., capping of contaminated soil) with attendant engineering controls.

Where applicable, project managers should consider continuing atmospheric and other background contributions to sites (U.S. EPA 2002c). *EPA's Contaminated Sediment Strategy* (U.S. EPA 1998a) includes some discussion of EPA's strategy for abating and controlling sources of sediment contamination. Source control activities may be implemented by governmental entities using combinations of site inspections, promotion of voluntary actions, technical assistance, onsite cleanup actions, and legal actions.

2.3.2 Early Action

Highlight 2-5 provides examples of early actions taken to control sources and other types of early actions at contaminated sediment sites. Early or interim actions are used frequently to prevent human or ecological exposure to contaminants or to control migration or redistribution of contaminated sediment. However, they do not generally preclude the need for additional cleanup actions at sites. Factors for determining which response components may be suitable for early or interim actions include the time frame needed to attain specific objectives, the relative urgency posed by potential or actual exposure, the degree to which an action may reduce site risks, and compatibility with likely long-term actions (U.S. EPA 1992b).

An early action taken under Superfund removal authority may be appropriate at a sediment site when, for example, it is necessary to respond quickly to a release or a threatened release of a hazardous substance. At contaminated sediment sites, removal authority has been used to implement many of the actions listed in Highlight 2-5. The NCP §300.415 outlines criteria for using removal authority, as further explained in the EPA guidance and directives (U.S. EPA 1993a, U.S. EPA 1996c, U.S. EPA 2000a). Project managers may also consider separating the management of source areas from other, less concentrated areas by establishing separate Operable Units (OUs) for the site.

2.4 CLEANUP GOALS

In order to select the most appropriate remedy for a site, it is imperative that clearly defined remedial action objectives (RAOs) be developed. RAOs are used in evaluating the clean-up options for the site and in providing the basis for developing more specific remediation goals (RGs) including contaminant-specific final sediment clean-up levels. RAOs, RGs, and clean-up levels are dependent on each other and represent three steps along a continuum leading from the scoping to the selection of a remedial action that will be protective and provide the best balance among the NCP nine criteria.

2.4.1 Remedial Action Objectives

RAOs provide a general description of what the cleanup is expected to accomplish, and help focus the development of the remedial alternatives in the feasibility study. RAOs are derived from the conceptual site model (section 2.1), and address the significant exposure pathways. RAOs may vary widely for different parts of the site, whether or not these parts are managed as separate OU's. For example, a sediment site may include a recreational area used by fishermen and children, as well as a wetland that provides critical habitat for fish and wildlife. Though both areas may contain similarly-contaminated sediment, the different receptors and exposure pathways may dictate that the project manager develop different RAOs for each area.

Highlight 2-5: Examples of Early Actions at Contaminated Sediment Sites

Actions to prevent releases of contaminants from sources include the following:

- Excavation or containment of flood plain soils or other source materials in the associated watershed
- Engineering controls (e.g., sheet pilings, slurry walls, grout curtains, and extraction) to prevent highly contaminated ground water or leachate from reaching surface water and sediment
- Engineering controls to prevent contaminated runoff from reaching surface water and sediment

Actions to prevent exposure to contaminants include the following (coordinated with the appropriate agencies):

- Access restrictions
- Fish consumption advisories
- Use restrictions and advisories for waterbodies
- Actions to protect downstream drinking water supplies

Actions to prevent further migration of contaminated sediment include the following:

- Boating controls (e.g., vessel draft or wake restrictions to prevent propeller wash, anchoring restrictions)
- Excavating, dredging, or capping of contaminated sediment hot spots (i.e., localized areas of high contaminant concentration)

The development of RAOs should also include a discussion of their basis and how the RAOs address all the unacceptable risks identified in the risk assessment. Examples of RAOs specific for sediment sites are included in Highlight 2-6. During development of RAOs project managers should evaluate whether the RAO is achievable by remediation of the site or if it requires additional actions outside the control of the project manager. For example, biota recovery which depends on cleanup of sources under other authorities may not be appropriate for site-specific RAOs. However, the project manager may discuss these other actions in the record of decision (ROD) and should consult with other agencies/authorities as appropriate.

2.4.2 Remediation Goals

Generally, preliminary remediation goals (PRGs) protective of human health and the environment are identified early in the remedial investigation process (at scoping meetings) based on readily available information [e.g., from the PA/SI (preliminary assessment/site inspection), NPL (National Priorities List) listing packages, or screening risk assessments]. As more information is generated during the RI, these PRGs are modified to incorporate an improved understanding of site conditions, resource use, human activities, and the nature and extent of contamination. However, the completed RI/FS should identify an appropriate remediation goal (or range of goals) for each contaminant of concern in each medium of significance. These remediation goals should be based on ARARs (if they exist), or on the site-specific baseline risk assessment. Currently, there are no federal ARARs for sediment media, and although some states have promulgated sediment clean-up standards, most RGs and clean-up levels for sediment are risk-based. RGs should represent as a range of acceptable risk levels so that the project manager may consider the NCP criteria when selecting the final cleanup levels. The size and shape of the risk range depends on

Highlight 2-6: Example Remedial Action Objectives for Contaminated Sediment Sites

Human Health:

- Reduce the risks to children and adults from the incidental ingestion of and dermal exposure to contaminated sediment while playing, swimming, or fishing at or near the site to acceptable levels
- Reduce the risks to adults and children from ingestion of contaminated fish taken from the site to acceptable levels

Ecological Risk:

- Reduce the toxicity to benthic aquatic organisms living at the surface water/sediment interface to levels that are acceptable
- Reduce the risks to birds and mammals that feed on fish that have been contaminated due to food chain transport from contaminated sediment to levels that are acceptable

the level of uncertainty associated with the reference dose and the exposure factors used. Remediation goals should be developed which acknowledge the following concepts:

- *Ecological risks:* Sediment remediation goals should be based on the site-specific no adverse effects level and the maximum acceptable adverse effects level; concentrations associated with these levels generally should form the lower and upper bounds, respectively, of the risk range for ecological effects;

- *Human health cancer risks:* Sediment remediation goals should be based on an excess upper bound lifetime cancer risk to an individual (based on a reasonable maximum exposure scenario) of between 10^{-4} and 10^{-6}. While the 10^{-6} risk level generally should be used as a point of departure for analysis of alternatives, other levels within this risk range may be helpful in evaluating different remedial strategies; and

- *Human health risk effects that result from systemic toxicity:* Sediment remediation goals should be based on levels to which human populations, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety. This generally means that levels should be determined through back-calculation from the appropriate Hazard Indices identified in the baseline risk assessment.

Baseline risk assessments provide an evaluation of the potential threat to human health and the environment in the absence of any remedial action or institutional controls. Generally, they provide the basis for determining whether remedial action is necessary as well as the framework for determining risk based remediation goals. Detailed guidance on evaluating potential human health and ecological impacts is provided in *Risk Assessment Guidance for Superfund*, also referred to as “RAGS,” (U.S. EPA 1989) and *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment*, also referred to as “ERAGS” (U.S. EPA 1997c). In addition, OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management Principles for Superfund Sites*

(U.S. EPA 1999b), provides risk managers with several principles to consider when making ecological risk management decisions.

The selection of assessment endpoints is a critical component of the ecological risk assessment. Once assessment endpoints have been selected, testable hypotheses and measurement endpoints can be developed to evaluate the potential threat to the assessment endpoints. Polychlorinated biphenyls (PCBs), for example, bioaccumulate in food chains and can diminish reproductive success in upper trophic level species (e.g., mink) exposed to contaminants through their diet. Therefore, reduced reproductive success in fish-eating birds and mammals may be an appropriate assessment endpoint. An appropriate measurement endpoint in this case might be contaminant concentrations in fish or in the sediment where the concentrations in these media can be correlated to reproductive effects in the top predator that eats the fish. The sediment concentration range associated with an acceptable level of reproductive success would constitute the remediation goal.

Site-specific data should be collected and used wherever practicable to develop RGs that are protective. For ecological risks, in order to identify appropriate goals, the risk assessor should use data from the same toxicity tests, population or community-level studies, tissue residue concentrations, or bioaccumulation models that were used to determine that there was an unacceptable ecological risk. As discussed in OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management for Superfund Sites Principles* (U.S. EPA 1999b), the data may be used to establish a concentration and response gradient to define the concentration range that represents an acceptable (i.e., protective) level of risk. At some small sites, however, responsible parties may determine that it is more cost effective and quicker to remove or contain all contaminated sediment rather than to conduct a full baseline risk assessment and generate a concentration and response gradient. There is no standard number that can be used in determining an acceptable level of adverse effects for the receptors to be protected (e.g., the LC_{50} from the sediment toxicity tests, a 25 percent reduction in benthic abundance, a 10 percent reduction in fish reproduction, the value used in dependent on the assessment endpoints selected and the measurement endpoints used). This level should be discussed by the risk assessor and risk manager as early as possible in the risk assessment process and should be coordinated with the trustees.

The EPA equilibrium-partitioning sediment guidelines (ESGs) or benchmarks and other published sediment guidelines [e.g., NOAA (National Oceanic and Atmospheric Agency) Screening Quick Reference Tables (SQuiRTs), available at http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html] are useful as screening values at Superfund sediment sites, but are not appropriate as default, site-specific RGs or clean-up levels. The Superfund program has also developed a set of screening values called Ecotox Thresholds (ETs) available at http://www.epa.gov/superfund/resources/ecotox/index.htm. EPA's *ECO Update on EcoTox Thresholds* (U.S. EPA 1996d) describes, in detail, how to use ETs as screening levels.

2.4.3 Cleanup Levels

At most sites, RGs are developed into final, chemical-specific, sediment cleanup levels by weighing the NCP balancing and modifying criteria and other factors relating to uncertainty, exposure, and technical feasibility. The nine NCP criteria (NCP §300.430) for remedy selection are discussed in Chapter 3, section 3.2.

As noted above, final cleanup levels for protection of human health are developed from the RGs by considering exposure factors, uncertainty factors, technical factors, and by weighing the NCP balancing and modifying criteria. Exposure factors that may be relevant to consider include (among others) cumulative impacts of multiple contaminants at the site as well as site-specific exposure information that can replace some generic assumptions. Uncertainty factors that may be relevant to consider include (among others) the reliability of inputs and outputs of the model to estimate risks and establish cleanup levels, reliability of alternatives to achieve those modeled results, and the likelihood of exposure scenarios. Technical factors include (among others) the ability to monitor and control movements of contaminants in the environment, technical limitations of remedial alternatives, and detection and quantification limits of contaminants in environmental media. All of these factors are considered when establishing final cleanup levels that are within the risk range.

The derivation of ecologically-based cleanup levels is a complex and interactive process balancing contaminant fate and transport issues with toxicological considerations and potential habitat impacts of the remediation alternatives. Before selecting a cleanup level, the project manager, in consultation with the ecological risk assessor, should consider at least the following factors (U.S. EPA 1999b):

- The magnitude of the observed or expected effects of site releases and the level of biological organization affected (e.g., individual, local population, or community);

- The likelihood that these effects will occur or continue;

- The ecological relationship of the affected area to the surrounding habitat;

- Whether the affected area is a highly sensitive or ecologically unique environment; and

- The recovery potential of the affected ecological receptors and expected persistence of the chemicals of concern under present site conditions.

Generally, the ROD should include chemical-specific cleanup levels as provided in the NCP §300.430(c)(2)(I)(A). The ROD should also indicate the approach that will be used to measure attainment of the cleanup level. Generally, the cleanup levels are an important piece of the performance standards designed to determine when the RAOs have been met. At some sites, however due to uncertainty in human health and ecological systems and models/data used to derive the cleanup levels or the contribution of other sources, the attainment of cleanup levels may not coincide with the attainment of RAOs. Where cleanup levels have been achieved but RAOs have not been met and are not expected to be met, it may be necessary to issue a ROD Amendment or Explanation of Significant Difference (ESD) to modify the remedy. The equivalent of a ROD Amendment in RCRA corrective action is the RCRA Permit Modification. Consistent with the NCP requirement (NCP §300.430(f)(4)(ii)), Superfund sites should be reviewed no less than every five years after initiation of the selected remedial action. Chapter 8, Remedial Action and Long-Term Monitoring, provides additional guidance on the information to be collected for this review to be effective.

2.5 SEDIMENT STABILITY

An important part of both the remedial investigation at many sediment sites is an assessment of the extent of sediment movement or transport by processes and events in the past and a prediction about whether there is likely to be significant movement in the foreseeable future. This topic has become known as an assessment of sediment stability. Sediment stability is also important to consider during the feasibility study and remedial design. It can be one of the most important factors in identifying areas suitable for monitored natural recovery, in-situ caps, or near-water confined disposal facilities (CDFs). This section focuses on the qualitative analyses of factors that affect a remedy's vulnerability to physical and biological forces and briefly introduces some quantitative tools that may be needed. A detailed guide to quantitative methods is not provided in this guidance as technical expertise in geomorphology, oceanography, hydrodynamic modeling, etc. is often required for applying these methods.

Most sediment sites are subject to some degree of contaminant movement, although the movement may be large or small. Both natural and man-made (anthropogenic) forces may cause sediment movement. Highlight 2-7 lists some examples of events which may disrupt sediment.

Highlight 2-7: Examples of Natural and Anthropogenic Causes of Sediment Movement

Natural causes include:

- Tides in marine waters and estuaries
- Floods
- Seiches (rapid oscillation of lake elevation caused by wind), especially in the Great Lakes
- Hurricanes
- Earthquakes, landslides, dam failures, and tsunami
- Pacific cyclones
- Ice thaw and ice dam-induced scour
- Bioturbation from micro- and macrofauna

Anthropogenic causes include:

- Boat propeller wash and ships' wakes
- Ship grounding and anchor dragging
- Navigational dredging and channel maintenance
- Placer mining, and sand and gravel mining
- Intentional removal or breaching of hydraulic structures such as dams, dikes, weirs, groins, and breakwaters
- In-water construction such as bridge supports

Anthropogenic and natural forces may differ greatly in frequency (e.g., daily tides or frequent ship traffic versus infrequent navigational dredging or storm surges) and intensity (e.g., bioturbation versus storm-generated waves). It is the origin, frequency, and intensity of a given force which must be assessed collectively when determining the potential impacts of the force on sediment stability and/or contaminant mobility.

Project managers should recognize that there may be a difference between sediment stability and contaminant mobility. While these two concepts are interrelated and often discussed simultaneously, contaminant mobility and availability are not exclusively related to the transport and movement of sediment. A stable sediment bed may not necessarily imply low contaminant availability, for example, if upward ground water flow is high and contaminants are mobilized. Conversely, small scale sediment movement may not necessarily imply high contaminant availability, for example if most contaminants are below the surface layer where most movement occurs.

The physical processes governing sediment stability are complex and understood with varying levels of certainty. There are a variety of empirical methods for evaluating sediment stability in the field and a variety of numerical modeling methods for evaluating events for which there is no field record for predicting future stability. Each of the empirical methods and models have limitations, so it is critical to include a variety of methods in evaluating a site and to compare the results of each method. For large or complex sediment sites, project managers should approach an assessment of sediment stability from the following aspects:

- An assessment of empirical site characterization data (see section 2.5.1);

- An assessment of the origins, frequencies and intensities of expected disruptive forces at the site (see sections 2.5.2 and 2.5.3);

- Fate and transport modeling of sediment and contaminants (see section 2.5.6); and

- An assessment of the expected consequences or results of expected sediment movement and transport (see section 2.5.4).

Where multiple lines of evidence point to similar conclusions, project managers may have more confidence in their predictions. Where the lines of evidence do not concur, project managers should bring their technical experts together, determine the source of the discrepancies, and reach a decision.

2.5.1 Empirical Data on Sediment Stability

An assessment of the past impacts of forces on sediment stability begins with the collection of a variety of empirical data (i.e., data derived from field or laboratory observation). The vertical and horizontal sediment distributions present at a site are a result of all of the routine and extreme, natural, or anthropogenic, forces that contribute to the physical, chemical, and biological attributes of a waterbody. Site conditions at the time of evaluation reflect a combination of influences. Project managers should not assume that current conditions represent stable conditions when, in fact, sediments may be actively responding to recent or current forces and/or events. Conversely, project managers should not assume that a site or all areas of a site are unstable or unstable at a scale which significantly impacts contaminant release.

Forces that are important in terms of their larger scale influences on watershed characteristics may be less important to the stability of sediment in smaller, more isolated areas of a waterbody. Both scales of investigation are important. For example, in some situations, the large scale rainstorms associated with hurricanes may greatly impact sediment loading to the waterbody, but have little effect on stability of the sediment bed itself. When considering the potential impacts of disruptive forces on sediment movement, it is important to assess these forces as they relate to the overall watershed and in terms of current and future site characteristics.

Many site characteristics affect sediment stability, but primary among them are the shear stress at the bottom of the waterbody during various conditions, and the properties (e.g., cohesiveness) of the upper sediment layers. In most environment, bottom shear stress is controlled by currents, waves, and bottom roughness (e.g., sand ripples, biologically-formed mounds in fines). In some environments, suspended sediment (often present during floods) or a fluff, floc, or low density mud layer (present in some estuaries and lakes) may decrease the erosion of underlying sediment. This is sometimes known as "dynamic armoring."

Sediment properties that affect erosion in many sediment environments include bulk density, particle size (average and distribution), mineralogy (especially clay mineralogy), the presence of gas, and the organic content (amount and type). Erosion rates typically vary by 2 to 3 orders of magnitude spatially at a site, depending on currents, bathymetry, and other factors. In a fairly uniform cohesive sediment core, erosion rates may drop several orders of magnitude with depth, but in more variable cores this is not the case. Armoring (winnowing of fine material from the sediment surface) can significantly reduce the erosion of mixed and cohesive sediment.

Biological processes by macro- and microorganisms also affect sediment stability in multiple ways, both to increase erosion (e.g., by lowering bulk density) and to decrease erosion (e.g., aquatic vegetation, floc effects, biochemical reactions increases shear strength of sediment). The process of sediment mixing caused by bioturbation is discussed further in section 2.5.3.

Highlight 2-8 lists examples of empirical methods which may be useful to assess sediment stability.

2.5.2 Hydrodynamic Forces

The majority of naturally occurring hydrodynamic forces such as those generated by wind, waves, currents, and tides, occur with great predictability and significantly influence sediment characteristics and movement (Hall 1994). While these routine forces seldom cause changes that are dramatically visible, they may be the events causing highest shear stress and therefore the most important factors in controlling the physical structure of a given waterbody. It is important to note that seasonal, or other changes in water flow may affect where erosion and deposition occur. Depending on the location of the site, (e.g., riverine areas, coastal/marine area, inland waterbodies), different waterbody factors will play important roles in determining sediment movement. To determine the frequency of particular routine forces acting upon sediment, project managers should obtain historical records on water currents and other hydrodynamic forces, especially those from nearby gauging stations. While the intensity of these routine forces may be low, their high frequency may cause them to be the primary control of sediment movement within some waterbodies.

Highlight 2-8: Empirical Methods to Evaluate Sediment Stability

Bathymetry (comparing sediment surface elevations to known datum):

- Single point/local area devices
- Transects/cross-sections (with known vertical and horizontal accuracy)
- Longitudinal river profiles
- Acoustic surveys (with known vertical and horizontal accuracy)
- Comparison to dredging records, air photos, overall geomorphology

Geochronology (age-dating segments of cores):

- Cs^{137}, Pu^{239}, Pu^{240}, lignin, stable Pb (longer-lived species to evaluate burial rate and age progression with depth)
- Pb^{210}, Be^{7}, Th^{234} (shorter-lived species to evaluate depth of mixing zone)
- X-radiography, color density analysis

Contaminant data (from cores, surface sediments, and water column):

- Time-series observations (event scale and long-term seasonal, annual, decade-scale)
- Comparison of core pattern with pollutant loading history
- Comparison of temporal patterns in surface sediment with pollutant loading history (accounting for response time)
- Comparison of concentration patterns during and after high energy events

Geomorphological studies:

- Spacial and temporal variability
- Human modifications

Sediment-contaminant mass balance studies during high energy events:

- Upstream and tributary loadings (grain size distributions and rating curves)
- Tidal cycle sampling (in marine estuaries)
- Sampling during the rising hydrograph (frequently greatest erosion)

In contrast, some waterbodies are significantly affected by extreme forces generated by short time frame and less common events. In many cases, these “extreme” forces originate by the same mechanisms as “routine” forces (e.g., wind) but are significantly stronger than routine conditions and capable of moving large amounts of sediment. Some extreme events, however, have no routine event counterparts (e.g., earthquakes). Meteorological events, such as hurricanes, may move large amounts of sediment in coastal areas due to storm surges and unusually high tides that cause flooding. Flooding may occur from snow-melt and other unusually heavy precipitation events resulting in the movement of large amounts of sediment. Scour, resulting from the movement of ice and/or natural or man-made debris, may also be an important consequence of a flood event.

While the existence of extreme hydrodynamic forces are generally predicable within particular climatic settings, they are commonly viewed as unforeseeable. What is actually unknown is the precise points in time in which they will occur and whether their frequency may change through time. To obtain a preliminary understanding of extreme event frequency at a site, it is important to examine both the historical records and site characterization data (such as core and bathymetry data).

Floods are frequently classified by their probability of occurrence; for example 50-year, 100-year, 200-year, and probable maximum flood. While the term "100-year flood" suggests a time frame, it is in fact a probability expression that a flood has a one percent probability of occurring (or being exceeded) in any year. Similarly, 200-year flood refer to a flood with a 0.5 percent probability of occurring in any year. However, it is not uncommon for multiple low probability events to happen more frequently than they are expected, especially where the record upon which they were based is not very long or where climate is shifting. Probable maximum flood refers to the most extreme flood that could theoretically occur based on maximum rainfall and maximum runoff in a watershed.

It is important to consider the intensity of extreme hydrodynamic forces as well as their frequency. Intensity is a measure of the strength, power or energy of a force. The intensity of a force will be a significant determinant of its possible impact on the proposed remedy. Tropical storms (including hurricanes) are often classified according to their intensity, that is, the effects at a particular place and time which is a function of both the magnitude of the event and the distance from it. Tropical storms such as hurricanes are commonly classified by intensity using the Saffir-Simpson Scale of Category 1 to Category 5 tropical storms. Other physical forces and events, such as earthquakes, may be classified according to magnitude, that is a measure of the strength of the force or the energy released by it. Earthquakes are most commonly classified in this way (e.g., the Richter scale) although they may also be classified by intensity at a certain surface location (e.g., the Modified Mercalli scale).

For sites in areas which may be affected by extreme events, project managers should assess the record of occurrence near the site and determine the appropriate category or categories for analysis. At a minimum, project managers should evaluate the impacts of a 100-year flood and other events or forces with a similar probability of occurrence (i.e., 0.01 in a year) on sediment stability. A U.S. Geological Survey (USGS) fact sheet explaining the 100-year flood is in Appendix B. At some sites, especially where human and ecological risk is high, it may be appropriate to analyze the effects of events with lower probabilities. Recorded characteristics of physical events, such as current velocities or wave heights, may provide project managers with parameters needed to calculate or model sediment movement. If information from historical records is insufficient or the historical record is too short to be useful, project managers should consider obtaining technical assistance to model a range of potential events to estimate effects on sediment movement and transport. Section 2.6 of this chapter discusses modeling in more detail.

A variety of information resources are available on the Internet, which may assist the project manager in evaluating sediment movement in response to hydrodynamic forces (Highlight 2-9).

Highlight 2-9: Flood Data Information Resources	
Tropical Storms	http://www.nhc.noaa.gov
State Flood Data	http://water.usgs.gov
USGS Historical Notional Water Information System Web Site (NWIS) Data Retrieval for the United States	http://waterdata.usgs.gov/nwis-w/US/
Heavy Precipitation and High Streamflow in the United States	http://www.ncdc.noaa.gov/ol/climate/severeweather/rainfall.html
USGS Real-Time Water Data	http://water.usgs.gov/realtime.html

2.5.3 Bioturbation

The most important natural process causing sediment movement within otherwise stable sediment deposits is bioturbation. Broadly speaking, bioturbation is the movement of sediment by the activities of aquatic organisms. While many discussions of bioturbation are focused on sediment dwelling animals, such as worms and clams, bioturbation may also include the activity of larger organisms such as fish and aquatic mammals. The effects of bioturbation can include the mixing of sediment layers, alteration of chemical forms of contaminants, bioaccumulation and transport of contaminants from the sediment, and/or a reduction in the effectiveness of a remedy based on in-situ capping or monitored natural recovery based on natural sedimentation.

Many bottom-dwelling organisms also physically move sediment particles during activities such as locomotion, feeding, and shelter building. These activities may alter sediment structure, biology, and chemistry, but the extent and magnitude of the alteration depends on site location, sediment type, and the types of organisms and contaminants present. For purposes of a sediment stability analysis, the factor of most concern is the depth to which significant physical mixing of sediment takes place, sometimes known as the “mixing zone.” The mixing zone is best determined by examination of sediment cores. However, it is also useful to be aware of the typical burrowing depths of aquatic organisms in environments similar to the site.

Typically, the upper 5 to 15 centimeters of sediment contain the greatest number of organisms and activity, and are therefore of greatest interest when attempting to determine the mixing zone or when evaluating current exposure of biota to contaminants. However, project managers should also consider the activity type, the intensity of the activity, and organism population density, when determining the extent to which bioturbation should be considered in site evaluation. Highlight 2-10 provides examples of organisms that cause bioturbation, their activity type, and the general depth of the activity.

A project manager should be aware of at least the following parameters when assessing the depth of the mixing zone and the potential role bioturbation will play on a given sediment bed:

- Site location (e.g., salinity, water temperatures, depths, seasonal variation);

- Sediment type (e.g., size distribution, organic and carbonate content, bulk density); and

- Organism type (e.g., organisms either present and/or likely to recruit to and recolonize the area).

Highlight 2-10: Example Depths of Bioturbation Activity

Organism	Activity Type	Depth	Reference
Freshwater			
Tubificid worm (oligochaete)	Burrowing/Feeding	2 cm - 3 cm	Pennak 1978
Mayfly (insect)	Burrowing	5 cm - 15 cm	Pennak 1978
Crayfish (crustacean)	Burrowing	5 cm - 3 m	Pennak 1978
Burbot (fish)	Burrowing	0 cm - 30 cm	Boyer et al. 1990
Marine/Estuarine (Atlantic Coast)			
Bristleworm (polychaete)	Burrowing	0 cm -15 cm	Hylleberg 1975
Bamboo worm (polychaete)	Burrowing/Feeding	0 cm - 20 cm	Rhoads 1967
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977
Marine/Estuarine (Pacific Coast)			
Bristleworm (polychaete)	Burrowing	0 cm - 15 cm	Hylleberg 1975
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977

This analysis may be done for naturally deposited sediment as well as potential in-situ capping material. Where bioturbation is likely to be a significant process, it is important to evaluate its effects using site-specific data and assistance by technical experts.

2.5.4 Predicting the Consequences of Sediment Movement

Depending on its extent, movement or disturbances of contaminated sediment or in-situ cap material may or may not have significant consequences for risk, cost, or other factors important at a specific site. A number of differing factors may be important in determining whether expected or predicted movements or disturbances are acceptable. Historical records or monitoring data for contaminant concentrations in sediment and water during events such as floods may be valuable in analyzing the increase in risk. Where this information is not available or has significant uncertainty, models may also be very useful. This analysis should include not only increased risk from contaminant releases to the waterbody, but wherever those contaminants are likely to be deposited. Increased cost may include remedy costs such as cap repair or costs related to contaminant dispersal, such as increased disposal cost of downstream navigational dredging. There may also be societal or cultural impacts of contaminant releases the project manager should consider, such as lost use of resources. These factors are discussed further in Chapter 1, section 1.6, Community Involvement.

Project managers should assess the impacts of contaminant release caused by sediment movement on potential receptors on a site-specific basis. Most of the needed information concerning human and environmental receptors is the same information that is gathered during the baseline risk assessment, and project managers should consult the site risk assessors for assistance. Where natural recovery is being evaluated, project managers should recognize that not only the rate of sediment burial, but also the frequency of sediment movement, determines the rate of recovery for surface sediment and biota. Where in-situ capping is being evaluated, project managers should recognize that some amount of transport may be acceptable and incorporated into plans for remedial design and cap maintenance. Increased risk due to sediment transport during dredging is a related analysis when considering dredging. Comparing the increased risk, cost, or other consequences of sediment disruption due to natural causes or the remedy itself is an important part of the remedy selection process.

When evaluating in-situ remedy alternatives, the significance of potential harm due to re-exposure of contaminated sediments or contaminated sediment redistribution is an important consideration. Factors to be considered include the nature of the contaminants, the nature of the potential receiving environment and biological receptors, and the potential for repair or recovery from the disturbance. These factors can be used to evaluate risks, costs, and/or other effects of different events on existing contaminated sediment or sediment remedies.

2.6 MODELING

This section briefly discusses the role of contaminated sediment transport and fate modeling in evaluating alternative risk management options at sediment sites. It is intended to assist project managers in deciding whether models can be a useful tool at a site, and if so, what type of model (or level of analysis) should be considered. This section does not advocate the use of models at every site, nor does it recommend specific models. Whether to use a model and what model to use are site-specific decisions for which modeling experts should be consulted. Guidance on the recommended process to follow in making these decisions is given below. Technical assistance is available to project managers from EPA's Office of Research and Development (ORD). Project managers should contact the ORD liaison in their region or the Office of Emergency and Remedial Response (OERR) for information about the appropriate laboratory and personnel for assistance. Additional research about contaminated sediment modeling is underway at ORD and project managers should monitor the EPA web site or contact their ORD liaison for more information.

There is a wide range of assessment techniques, empirical models, and more robust computer (i.e., multi-dimensional numerical) models that can be applied to contaminated sediment sites. Numerical models are frequently applied to the most complex sites. These sites typically have a long history of data collection and have documented contaminant concentrations in sediment and biota and often have fish consumption advisories already in place. In addition, cleanup has often been delayed at these sites because of the spatial magnitude of the problem, potential costs associated with remediation, and difficulty of decision-making due to the complexity of the issues.

Models are useful tools, but they can be very time consuming and expensive to apply at complex sediment sites. Most modeling efforts require large quantities of site-specific data and typically a team of experienced modelers. Nevertheless, models are helpful in that they give, when properly applied, a more complete understanding of the transport and fate of contaminants than can be provided by empirical data (from field or laboratory) alone. Modeling of contaminated sediments, just as with other modeling, should follow a systematic planning process that involves examination of data quality objectives (or other measures), uncertainty, and specific hypothesis. In most cases, models are expected to complement environmental measurements and address gaps that exist in empirical information. Examples of the uses of models include the following:

- Illustrating how contaminant concentrations vary spatially at a site. Empirical information can provide useful benchmarks that can be interpolated or modeled to get a better understanding of the distribution of contaminants;

- Predicting contaminant fate and transport over long periods of time (e.g., multiple years) or during episodic, high-energy events (such as a tropical storm or low-frequency flood event);

- Predicting future contaminant concentrations in sediment, water and biota to evaluate relative differences among the proposed remedial alternatives, ranging from monitored natural recovery to extensive removal; and

- Comparing modeled results to observed measurements to show convergence of information. Both modeling results and empirical data will have a measure of uncertainty, and modeling can help to examine the uncertainties (e.g., through sensitivity analysis) and refine estimates (which may include where to sample next).

The use of models at sediment sites is not limited to the remedy selection phase. Most sites that do use models for evaluation of proposed remedies are those that have previously developed a mass balance or other type of model during the development of the baseline risk assessment to quantify the relationships among contaminant sources and exposure pathways. At these sites, the same model is generally used to predict the response of the system to various cleanup options. Where this is done, it is important to continue to test the model predictions by monitoring during the remedy implementation and post-remedy phases to assess whether cleanup is progressing as predicted.

2.6.1 Sediment Transport Model Characteristics

A sediment transport model is a mathematical or conceptual representation of the movement of sediment and associated contaminants, as governed by physical, chemical and biological factors, in bodies of water. As such, a sediment model is limited by our current understanding of these factors and the ability to quantify (i.e., represent mathematically, their interactions and effects on the transport and fate of sediment). Thus, a sediment model is a relatively simplistic representation of the movement of sediment through natural and engineered waterbodies. It is simplistic due to the following

- Limitations in our understanding of natural systems, as reflected in the current state-of-the-science;

- Empiricism inherent in predicting flow-induced sediment transport, bank erosion, and non-point source loads;

- The relatively coarse spatial and temporal discretization (breaking space and time into blocks) of the waterbody being modeled when using a numerical model; and

- The inability to simulate geomorphological processes such as river meandering, bank erosion, and localized effects due to, for example, fallen trees and beaver dams.

Nevertheless, generally sediment transport models are the following:

- Useful tools when properly applied, although not required at every site;

- Data intensive, and require specialized expertise to apply and interpret; and

- One of several tools that should be used in making a remedial decision, not a stand-alone decision-maker

There are two basic types of sediment transport models, conceptual and mathematical models. In addition there are several different types of mathematical models. General types of models are described in Highlight 2-11 and an example of a conceptual site model is presented in Highlight 2-12.

Highlight 2-11: Types of Sediment Transport Models

Conceptual Model:

Identifies the 1) contaminants of potential concern, 2) sources of the contaminants, 3) physical and biogeochemical processes and interactions that control the transport and fate of sediment and associated contaminants, 4) exposure pathways, and 5) ecological and human receptors.

Mathematical Model:

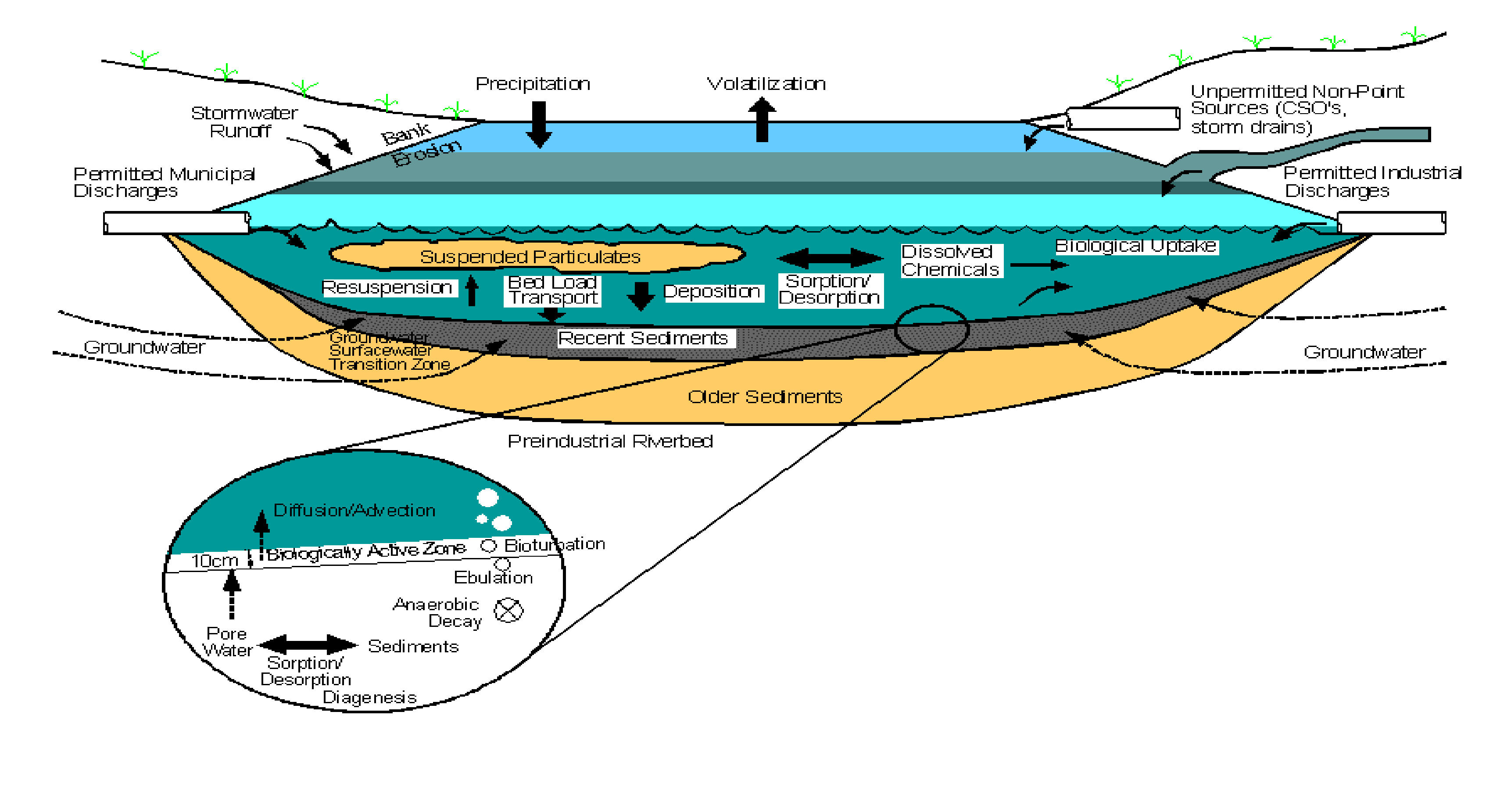
A set of equations that quantitatively represent the processes and interactions identified by the conceptual model that govern the transport and fate of sediment and associated contaminants. Mathematical models include analytical, regression, and numerical models:

- <u>Analytical Model:</u> An analytical model is one or more equations (e.g., simplified - a linearized, one-dimensional form of the advection-diffusion equation) for which a closed-form solution exists. This type of model would not be applicable at most sediment sites due to the complexities associated with the forcing hydrodynamics and spatial and temporal heterogeneities in sediment and contaminant properties/characteristics.

- <u>Regression Model:</u> A regression model is a statistically determined equation that relates a dependent variable to one or more independent variables. A stage-discharge rating curve is an example of a regression model in which stage (e.g., water level) and discharge (e.g., amount of water flow) are the independent and dependent variables, respectively.

- <u>Numerical Model:</u> In a numerical model, an approximate solution of the set of governing differential equations is obtained using a numerical technique. Examples include finite difference and finite element methods. A numerical model is used when the processes being modeled involve nonlinear equations for which closed-form solutions do not exist. Therefore, the solution obtained is an approximate solution.

Highlight 2-12: Conceptual Site Model Focusing on Sediment-Water Interaction



Source: Sediment Management Workgroup (SMWG)

2.6.2 Determining Whether A Mathematical Model is Needed

Mathematical sediment transport models can be time-intensive and expensive to apply, both in terms of costs to collect the data required for the models as well as to perform the modeling study, and their use and interpretation generally require specialized expertise. Because of this, mathematical modeling is not recommended for every sediment site. In some cases, empirical data from historical sources and new monitoring data may be sufficient to support a decision. A mathematical modeling study may not be recommended for very small (i.e., localized) sites, where cleanup may be relatively easy and inexpensive. However, mathematical modeling would generally be recommended for large or complex sites, especially where it is necessary to predict contaminant transport and fate over extended periods of time to evaluate relative differences among possible cleanup methods. Mathematical modeling becomes especially important when the existing empirical data are insufficient to predict future scenarios, as is frequently the case.

Project managers can decide whether a mathematical model is useful at a site by answering the following series of questions:

- Have the questions or hypotheses used to test the model been determined?
- Are historical data and/or simple quantitative techniques available to answer these questions with the desired accuracy?
- Have the spatial extent, heterogeneity and levels of contamination at the site been defined?
- Have the sources of sediment contamination been defined?
- Do sufficient data exist to support the use of a mathematical model, and if not, are time and resources available to collect the required data to achieve the desired level of confidence in model results? and
- Are time and resources available to perform the modeling study?

If the decision is made that some level of modeling is appropriate, the following section should assist project managers in deciding what level of analysis (i.e., what type of model) should be used.

2.6.3 Determining the Appropriate Level of Model

When the decision is made that a mathematical model is needed at a site, project managers generally should use three steps in determining what level of modeling is most appropriate. It is important that all three steps be followed in order.

<u>Step 1: Develop Conceptual Site Model</u>

Development of a Conceptual Site Model (CSM) is the key first step in this process. As described in section 2.1, Site Characterization and Conceptual Site Models, a CSM identifies the processes and interactions that control the transport and fate of sediment and associated contaminants. If this step is not performed, then the decision of what level of modeling is appropriate will be made with less than the requisite information needed to make a scientifically defensible decision.

The development of a CSM requires examination of all existing site data to assist in determining the significant physical and biogeochemical processes and interactions. Relatively simple quantitative expressions of key transport and fate processes using existing site data, such as presented by Reible and Thibodeaux (1999), may help in identifying those processes that are most significant at the site.

Step 2: Determine Processes that Can and Cannot be Modeled

This step concerns determining if all the processes and interactions that control the transport and/or fate of contaminated sediment, as identified in the CSM, can be simulated with one or more existing sediment transport and fate models. If it is determined that there are existing models capable of simulating at a minimum the most significant (i.e., first-order) processes and interactions, then the project manager should (using the appropriate technical experts) identify the types of models (e.g., analytical, regression, numerical) that have this capability. This will eliminate those types of models that do not have this capability from further consideration.

Mathematical models (in particular numerical models) have been developed that can simulate most of the processes that control the transport and fate of sediment and contaminants in waterbodies, including a wide variety of physical, chemical, and biological processes. Highlight 2-13 depicts the inter-relationship of some major processes and the type of model with which they are associated. Depending on the needs at the site, models or model components ("modules") may link many of these processes into one model. Examples of the processes that can be modeled include the following:

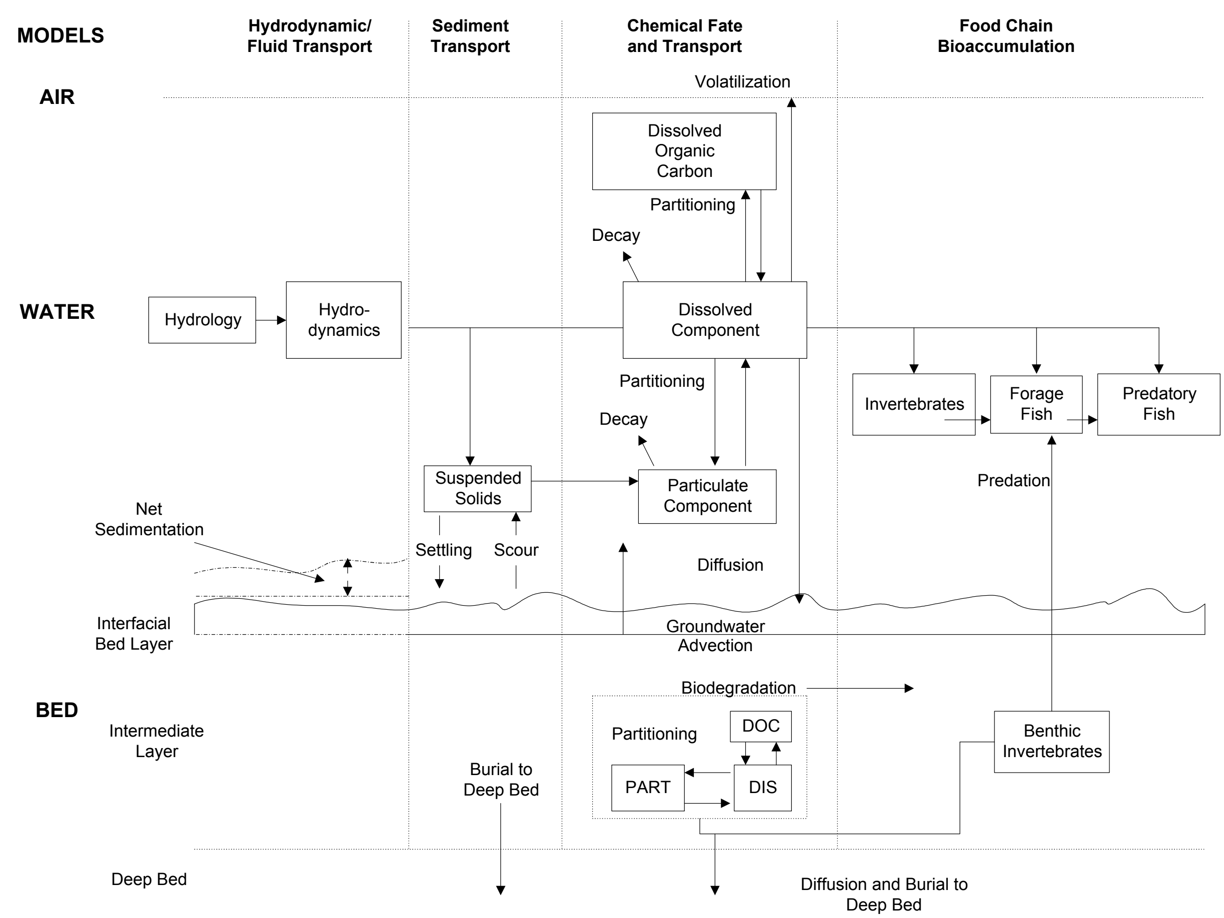
- On land and in the air, physical processes that result in loading of contaminants to water bodies may include point discharges, overland flow, discharge from ground water, and air deposition;

- In the water column, physical processes that may result in movement of dissolved or sediment-sorbed contaminants include transport via the water's ambient flow (advection), diffusion, and settling of sediment particles containing sorbed contaminants;

- In the sediment bed, important physical processes include the movement of pore water and dissolved contaminants, seepage into and out of the sediment bed and banks, and the mixing of dissolved and sediment-sorbed contaminants by bioturbation. In addition, both sorbed and dissolved material may be exchanged between the water column and sediment bed due to sediment deposition and resuspension or erosion; and

- In the water column and in the sediment bed, physiochemical processes influencing the fate and transport of contaminants include two-phase and three-phase chemical partitioning as described below. Biogeochemical reaction processes influencing the fate of contaminants include speciation, volatilization, anaerobic gas formation, hydrolysis, oxidation, photolysis, biodegradation, and biological uptake.

Highlight 2-13: Contaminant-Exposure Modeling Framework



Source: (NRC 2001)

In two-phase partitioning, the total concentration of the contaminant is defined as the sum of the dissolved and particulate fractions, whereas the partition coefficient is defined as a distribution coefficient in terms of the total suspended solids (TSS). The dissolved fraction is specified by the distribution coefficient and the TSS concentration. In three-phase partitioning, a contaminant is partitioned into three forms as a bio-available dissolved phase, a non-available dissolved organic carbon phase, and a particulate organic carbon phase. A three phase model is appropriate for waters in which internally produced organic material is a significant proportion of total solids as compared to solids supplied by watershed runoff, bank and bed erosion.

If it is determined that there are no existing models capable of simulating, at a minimum, the most significant (i.e., first-order) processes and interactions, then project managers may need to rely on other tools or methods for evaluating proposed cleanup methods or develop and test new models or modules. This latter approach is a research and development level effort and should be avoided if at all possible.

Examples of processes that cannot be dynamically simulated, even using state-of-the-art sediment transport models, are geomorphological processes such as the development of meanders in streams and rivers, and bank cutting/erosion. There are empirical methods for estimating the total quantity of sediment that would be introduced to a waterbody due to the failure of a river/stream bank, but this process cannot be dynamically simulated.

Step 3: Select an Appropriate Model

If one or more models or types of mathematical models exist that are capable of simulating the controlling transport and fate processes and interactions, then project managers should use the process described above to choose the appropriate type of model (i.e., level of analysis). If the decision is made to apply a numerical model at a sediment site, selection of the most appropriate contaminated sediment transport and fate model to use at a specific site is one of the critical steps in a modeling program. During this process, familiarity with existing sediment transport models is essential. Comprehensive technical reviews of available models are currently being conducted by the EPA's National Exposure Research Laboratory.

Where numerical models are used verification, calibration, and validation are critical to attaining useful results. The project manager should be aware that the terms "verification" and "validation" are frequently used interchangeably in modeling literature. These terms, as used in this guidance, are defined as follows:

- *Model verification*: Evaluating the theory, consistency of the computer code with model theory, and evaluation of the computer code for integrity in the calculations. (This is an on-going process, especially for newer models.);

- *Model calibration*: Using site-specific information from a historical period of time to adjust model parameters to more accurately reflect measured site-specific conditions; and

- *Model validation*: Demonstrating that the calibrated model accurately reproduces known conditions over a different period of time or in a different waterbody than that used for calibration.

The extent of verification, calibration, and validation in large part determines the accuracy of a model. If a verified model has not been calibrated or validated to a specific site, then its use may be of little value. Where possible, project managers should use verified and validated models that are in the public domain, calibrated to site-specific conditions. Proprietary models may also be useful, but project managers should be aware that they contain code that has not been shared publically and may not have been verified. The interpretation of modeling results and the reliance placed on those results should heavily consider the extent of model verification, calibration, and validation.

2.6.4 Peer Review

It is EPA policy that a peer review of numerical models is often necessary to ensure that a model provides decision makers with useful and relevant information. Project managers should use EPA's *Guidance for Conducting External Peer Review of Environmental Regulatory Models* (U.S. EPA 1994a) and *Peer Review Handbook* (U.S. EPA 2000b) whenever a numerical model is used to determine whether a peer review is appropriate and, if so, what type of peer review should be used. As a rule of thumb, major scientifically and technically based work products that support Agency decisions normally should be peer reviewed. In addition, when a model is being used outside the niche for which it was developed, is being applied for the first time, or is critical to a decision that is very costly, a peer review may be needed. In addition, project managers should refer to OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediments at Hazardous Waste Sites*, Principle 6 (Appendix A).

The EPA (1994a) also noted that: "Environmental models (i.e., fate and transport, estimation of contaminant concentrations in soil, ground water, surface water and ambient air, exposure assessment) that may form part of the scientific basis for regulatory decision making at EPA are subject to the peer review policy. However, it cannot be more strongly stressed that peer review should only be considered for judging the scientific credibility of the model including applicability, uncertainty, and utility (including the potential for misuse) of results and not for directly advising the Agency on specific regulatory decisions stemming in part from consideration of model output."

Highlight 2-14 summarizes some important points to remember about modeling at sediment sites.

Highlight 2-14: Points to Remember about Modeling at Sediment Sites

- Consider the range of available historical data that can be used in assessment techniques or models. Determine the level of model to be applied, commensurate with the issues and questions being raised
- Decide early whether to use models. If models are useful, seek assistance from modeling experts early in the site characterization process; for example, when scoping the RI and planning data collection efforts
- Choose models and model components appropriate to the scope of the questions that need to be answered. Simpler questions may be best answered by simpler models or other assessment techniques
- Concentrate site-specific data collection on factors that most influence model outcome. For some parameters, use of conservative "bounding" assumptions can replace site-specific data. For other parameters, site-specific data are important
- Be aware of the uncertainties and variability of model predictions. Where possible, quantify these using sensitivity analysis or other evaluation methods
- Consider the extent of model validation, calibration, and verification when assessing model results. Where possible, use validated and verified models that are in the public domain, calibrated to site-specific conditions
- Compare model predictions to monitoring results during and after remedy implementation to test model assumptions. Such comparisons provide insight as to the performance of individual models and provide a basis for model adjustments that improves model performance
- Where a model is being applied outside the niche for which it was developed, is being applied for the first time, or is being applied to help make decisions that are very costly, critical aspects of the modeling study should be peer-reviewed

3.0 FEASIBILITY STUDY CONSIDERATIONS

TABLE OF CONTENTS

HIGHLIGHTS

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3.0 FEASIBILITY STUDY CONSIDERATIONS

Generally, the purpose of a feasibility study for a contaminated sediment site is to develop and evaluate a number of alternative methods for achieving remedial action objectives. This process lays the groundwork for selecting a remedy for the site that best eliminates, reduces, or controls risks to human health and the environment. The general feasibility study process is described in the U.S. Environmental Protection Agency's (EPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, also referred to as the "RI/FS Guidance" (U.S. EPA 1988a). This chapter is intended to supplement existing guidance by offering sediment-specific guidance about developing alternatives, considering the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) criteria, identifying applicable or relevant and appropriate requirements, estimating cost, and using institutional controls. Chapters 4, 5, and 6 present more detailed guidance on evaluating alternatives based on the three major cleanup methods for sediment: monitored natural recovery (MNR), in-situ capping, and dredging (or excavation) with treatment or disposal.

3.1 DEVELOPING SEDIMENT ALTERNATIVES

The following steps, modified from EPA's RI/FS Guidance by adding details specific to sediment, generally apply to developing alternatives at sediment sites:

- Develop remedial action objectives specifying the contaminants and media of interest, exposure pathways, and cleanup goals that permit a range of alternatives to be developed including each of the three major cleanup methods (removal, capping, and natural recovery);

- Identify estimated volumes or areas of sediment to which the cleanup methods may be applied, taking into account the requirements for protectiveness as identified in the remedial action objectives and the chemical and physical characteristics of the site;

- Identify the time frame(s) in which the alternatives are expected to achieve cleanup goals and remedial action objectives;

- Develop additional detail concerning the equipment, methods, and locations to be evaluated for each of the three major cleanup methods (e.g., number and types of dredges or excavators, transport methods, treatment methods, type of disposal units, general disposal location, general cap materials, cap placement methods, detail concerning the processes being relied upon for natural recovery, need for monitoring and/or institutional controls); and

- Assemble the more detailed methods into a set of alternatives representing a range of removal, capping, and natural recovery options or combination of options, as appropriate.

This process is best done in an iterative fashion, especially at complex sites. For example, investigation into equipment and disposal options for sediment removal may lead to evaluation of a variety of time frames for achieving cleanup goals. The number and type of remedial alternatives that a project manager develops for any site is a site-specific decision. The project manager should take into account the size, characteristics, and complexity of the site. However, due to the limited number of cleanup methods available for contaminated sediment, generally project managers should evaluate each of the three major cleanup methods: monitored natural recovery, in-situ capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate.

3.1.1 Alternatives which Combine Cleanup Methods

At sites with multiple waterbodies or sections of waterbodies with different characteristics or uses, project managers have found that alternatives that combine a variety of cleanup methods are frequently the most promising. In many cases, institutional controls are also part of many alternatives (see section 3.5, Institutional Controls). The following examples illustrate a few ways cleanup methods have been combined into alternatives for evaluation at sediment sites:

- A variety of combinations of dredging, transport, and disposal methods have been developed as options for a variety of volumes of contaminated sediment "hot spot" areas combined with capping or MNR for the remainder of the site;

- Dredging has been developed as an option for areas that also require navigational dredging or for areas where there is insufficient water depth to maintain navigation with a cap, and capping has been developed for intertidal and under-pier areas where dredging may be infeasible and/or impractical; and

- Thin-layer placement (see Chapter 4, Monitored Natural Recovery) has been combined with MNR where the natural rate of sedimentation is insufficient to bury contaminants in a reasonable time frame

3.1.2 The No-Action Alternative

The NCP §300.430(e)(6) provides that the no-action alternative be developed as one of the alternatives under consideration at every site. The no-action alternative should reflect the site conditions described in the baseline risk assessment and remedial investigation. This alternative may be a no-further-action alternative if some removal or remedial action has already occurred at the site.

No-action or no-further-action alternatives should not include any treatment, engineering controls, or institutional controls but may include monitoring. However, a no-action alternative is different from a MNR alternative where natural processes are relied upon as a risk-reduction method.

If a no-action or no-further action alternative does not meet the NCP's threshold criteria of protection of human health and the environment and meeting applicable or relevant and appropriate requirements, it may be dropped from the detailed analysis of alternatives. However, the record of decision (ROD) should explain why the no-action alternative was dropped from the analysis.

Chapter 7, Remedy Selection Considerations, includes guidance on when it may be appropriate to select a no-action alternative.

3.1.3 In-Situ Treatment Alternatives

In-situ treatment is an experimental cleanup method that involves the biological, chemical, or physical treatment of contaminated sediment in place. Although significant technical limitations exist currently, active research and pilot studies in this field may make it a viable alternative in the future. Project managers are encouraged to watch the development of in-situ treatment methods for contaminated sediment. Potential in-situ treatment methods include the following:

- Biological Treatment: Microbial degradation of contaminants by the addition of enhancement materials such as oxygen and nutrients (e.g., nitrogen), or microorganisms into the sediment or a reactive cap;

- Chemical Treatment: The destruction of contaminants through oxidation and dechlorination processes by providing chemical reagents, such as permanganate, hydrogen peroxide, or potassium hydroxide, into the sediment or a reactive cap; and

- Immobilization Treatment: Solidification or stabilization by adding Portland cement, fly ash, limestone, or other additives to the sediment for encapsulating the contaminants in a solid matrix and/or chemically reducing the contaminants by converting them into a less soluble, less mobile, or less toxic form.

Techniques for in-situ treatment of sediment are in the early stages of development, and few methods are currently commercially available. Experiences gained to date in experimental or small-scale applications of in-situ remedies have indicated that technical limitations to the effectiveness of available in-situ treatments continue to exist. For example, in-situ remedies relying on the addition of required substrates and nutrients, reagents, or catalysts have been developed for some contaminants, such as polychlorinated biphenyls (PCBs), but no effective in-situ delivery system has been developed to deliver the needed reagents to contaminated sediment (NRC 2001). The lack of an effective delivery system has also hindered the application of in-situ stabilization systems (NRC 2001). However, new developments may make this a more promising cleanup method in the future.

Several EPA-funded bench and field studies in this area are underway. These include EPA's Superfund Innovative Technology Evaluation (SITE) program, which encourages the development and routine use of innovative treatment, monitoring, and measurement technologies. The SITE program is in the process of demonstrating in-situ treatment technologies (Highlight 3-1). More information on the SITE program is available at http://www.epa.gov/ORD/SITE/. Also, the Hazardous Substance Research Center (HSRC) - South-SouthWest, centered at Louisiana State University, has received funding for research about in-situ treatment and other innovative capping alternatives for contaminated sediment in the Anacostia River in Washington, D.C. More information on this program is available from the HSRC at http://www.hsrc.org.

3.2 NCP REMEDY SELECTION CRITERIA

The NCP §300.430(e)(9) establishes a framework of nine criteria for evaluation and selection of remedies. These criteria address the requirements and considerations of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and additional technical and policy considerations that have proven to be important for selecting remedial actions. Many of these

Highlight 3-1: SITE Program In-situ Treatment Technology Demonstrations

Site	Technology Type	Contaminant
Jones Island CDF	Phytoremediation	Polynuclear aromatic hydrocarbons (PAHs) and PCBs
Milwaukee Harbor	Phytoremediation	PAHs and PCBs
Whatcom Waterway	Electrochemical Oxidation	Mercury and PAHs
Bellingham Bay, Puget Sound	Electrokinetics	Phenolic Compounds
Pearl Harbor	Bioremediation	PCBs
Anacostia River	Multiple In-situ Caps	PAHs and PCBs

criteria are also of importance to the Resource Conservation and Recovery Act (RCRA). The NCP §300.430(e)(7) describes a method for screening potential alternatives prior to developing detailed alternatives when a large number of alternatives are being considered at a site. Only the alternatives judged as the best or most promising following this screening are retained for further development and for a detailed analysis. The three broad criteria for screening preliminary remedial alternatives are: 1) effectiveness; 2) implementability; and 3) cost. Although a screening level analysis may be necessary in some cases, due to the limited number of cleanup methods available for sediment, project managers generally should not screen out any of the major cleanup methods early in the FS.

More detailed discussions of what is included under each of the nine criteria can be found in the *Guide to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Decision Documents* (U.S. EPA 1999a) and the RI/FS Guidance. The following provides a summary of the nine criteria (U.S. EPA 1988a):

- *Overall Protection of Human Health and the Environment*: This criterion is used to evaluate how the alternative as a whole achieves and maintains protection of human health and the environment;

- *Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)*: This criterion is used to evaluate whether the alternative complies with chemical-specific, action-specific, and location-specific ARARs or if a waiver is justified. Although not a statutory requirement, this criterion also commonly includes whether the alternative considers other criteria, advisories, and guidance that are to be considered (TBC) at the site;

- *Long-Term Effectiveness and Permanence*: This criterion includes an evaluation of the magnitude of human health and ecological risk from untreated waste or treatment residuals remaining after remedial action has been concluded (known as residual risk), and the adequacy and reliability of controls to manage that residual risk. It also includes an assessment of the potential need to replace technical components of the alternative, such as a cap or a treatment system, and the potential risk posed by that replacement;

- *Reduction of Toxicity, Mobility, and Volume Through Treatment*: This criterion refers to the evaluation of whether treatment processes can be used, the amount of hazardous material treated, including the principal threat that can be addressed, the degree of expected reductions, the degree to which the treatment is irreversible, and the type and quantity of treatment residuals;

- *Short-Term Effectiveness*: This criterion includes an evaluation of the effects of the alternative during the construction and implementation phase until remedial objectives are met. This criterion includes an evaluation of protection of the community and workers during the remedial action, the environmental impacts of implementing the remedial action, and the expected length of time until remedial objectives are achieved;

- *Implementability*: This criterion is used to evaluate the technical feasibility of the alternative, including construction and operation, reliability, monitoring, and the ease of undertaking an additional remedial action if the remedy fails, the administrative feasibility of activities needed to coordinate with other offices and agencies, such as for obtaining permits for off-site actions, rights of way, and institutional controls, and the availability of services and materials necessary to the alternative, such as treatment, storage, and disposal facilities;

- *Cost*: This criterion includes an evaluation of direct and indirect capital costs, including costs of treatment and disposal, annual costs of operation, maintenance, monitoring of the alternative, and the total present worth of these costs, as discussed in section 3.4, Estimating Cost;

- *State (Or Support Agency) Acceptance*: This criterion is used to evaluate the technical and administrative concerns of the state (or the support agency, in the case of state-lead sites) regarding the alternatives, including an assessment of the state or the support agency's position and key concerns regarding the alternative, and comments on ARARs or the proposed use of waivers. Tribal acceptance is also evaluated under this criterion; and

- *Community Acceptance*: This criterion includes an evaluation of the concerns of the public regarding the alternative. It determines which component of the alternatives interested persons in the community support, have reservations about, or oppose.

3.3 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS FOR SEDIMENT ALTERNATIVES

Pursuant to CERCLA §121(d)(4), all remedial actions at CERCLA sites must be protective of human health and the environment and must comply with ARARs unless a waiver is justified. Cleanup levels for response actions under CERCLA generally are based on site-specific risk assessments, ARARs, and/or TBCs. ARARs may be waived only under limited circumstances. TBCs are generally non-promulgated advisories or guidance issued by federal, state or tribal governments that are not legally binding and do not have the status of potential ARARs. However, TBCs are considered along with ARARs as part of the site risk assessment and may be useful in developing CERCLA remedies. The project manager should also refer to *CERCLA Compliance with Other Laws Manual* (U.S. EPA 1988b).

Also, the preamble to the final NCP (55 FR 8741) states that, as a matter of policy, it is appropriate to treat Indian tribes as states for the purpose of identifying ARARs. See also NCP §300.515(b) for the conditions a tribal government should meet to be afforded substantially the same treatment as states.

The process of identifying ARARs typically begins in the scoping phase of the RI/FS, continues until the ROD is finalized, and may be reexamined during the five-year review process. ARARs include the following:

- Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations or facility siting law promulgated under federal, state, or tribal law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site; and

- Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal, tribal, or state law or facility siting law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

A requirement is applicable, or relevant and appropriate, but not both. Identification of ARARs should be done on a site-specific basis and usually involves a two-part analysis. First, a determination of whether a given requirement is applicable should be made, and second, if it is not applicable, then a determination should be made as to whether it is relevant and appropriate. Highlight 3-2 lists some examples of potential federal, state, and tribal ARARs for sediment sites and examples of how remedial strategies have been adapted to comply with ARARs.

On-site actions should comply with the substantive portions of ARARs unless the ARAR is waived. Compliance with administrative procedures, such as permits, is not required for on-site response actions. Off-site actions must comply with both substantive and administrative requirements of legally applicable laws and regulations.

For more information about ARARs, the project manager should consult guidance available at http://www.epa.gov/superfund, the *Compendium of CERCLA ARARs Fact Sheets and Directives* (U.S. EPA 1991a), and the *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b).

As part of the ARARs analysis, project managers, in consultation with the site attorney, should consider requirements promulgated under the Clean Water Act (CWA). For example, federal water quality criteria as well as state-promulgated regulations including state water quality standards may be potential ARARs for surface water. Some states may have water quality standards or their own promulgated sediment quality standards that may be potential ARARs for sediment.

Total maximum daily loads (TMDLs) established or approved by the EPA under the Clean Water Act are planning tools designed to reduce contributing sources of pollutants in water quality limited segments (WQLS). TMDLs calculate the greatest amount of loading of a pollutant that a waterbody can

Law or Regulation		
	Potential Federal ARARs	
Clean Water Act §304(a)	EPA publishes national recommended Ambient Water Quality Criteria (AWQC) for the protection of aquatic life and human health. CERCLA §121(d)(2) requires EPA eo consider whether nationally recommended AWGC should be relevant and appropriate requirements at a site. CERCLA §121(d)(2)(B) establishes the guidelines to consider in determining when AWQC may be relevant and appropriate requirements, including consideration of the designated or potential uses of surface water, the purposes for which the criteria were developed and the latest information available.	In developing a remedy for the upland soils portion of a sediment site, EPA determined that a revised AWQC was relevant and appropriate criteria for surface water runoff from the upland soils discharging to the waterway.
Clean Water Act §404 40 CFR 230	Regulates the discharge of dredged or fill materials into waters of the U.S. Discharges of dredged or fill materials are not permitted unless there is no practicable alternative that would have less adverse impact on the aquatic ecosystem. Any proposed discharge must avoid, to the fullest extent practicable, adverse effects, especially on aquatic ecosystems. Unavoidable impacts must be minimized, and impacts which cannot be minimized must be mitigated.	The Wycoff/Eagle Harbor, WA, NPL site included construction of a sheet pile barrier wall to control subsurface NAPL migration. To compensate for the loss of habitat, intertidal habitat was created in another part of the harbor by returning a diked off area to its historic intertidal character.
Rivers and Harbors Act, Section 10 33 CFR 320 to 323	Activities that could impede navigation and commerce are prohibited. Prohibits authorized obstruction or alteration of any navigable waterway.	A site with contaminated sediment has an authorized navigation depth of 30 feet. The evaluation of alternatives needs to consider the need to maintain this minimum depth when evaluating whether capping is or is not a feasible alternative for the entire site.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
Endangered Species Act	Section 7 requires federal agencies to ensure that the actions they authorize, fund or carry out are not likely to jeopardize the continued existence of endangered or threatened species, or adversely modify or destroy their critical habitat. Will be an applicable requirement where a threatened or endangered species or their habitat is or may be present. By policy, EPA consults with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (NMFS).	Chinook salmon are threatened species that are found at the Commencement Bay NPL site during part of the year. After following EPA's policy of consulting with the NMFS, EPA decides that to avoid harming the species, some in-water remedial work will be done only between August and February when juvenile salmon are not migrating through the area. Other in-water work will be performed between March and July, utilizing special conditions recommended by NMFS to minimize impacts to salmon.
Resource Conservation and Recovery Act (RCRA); 40 CFR 260 to 268	Dredged material may be subject to RCRA regulations if it contained a listed waste, or if it displays a hazardous waste characteristic, for example by the Toxicity Characteristic Leaching Procedure (TCLP). Most states have been authorized to implement the RCRA program in lieu of EPA. RCRA regulations may potentially be ARARs for the storage, treatment, and disposal of the dredged material unless an exemption applies. One such exemption is if CWA 404 applies to the cleanup activity (40 CFR 261).	The material to be dredged contains a listed pesticide formulation waste, and thus RCRA may be an applicable ARAR. However, CWA §404 applies to the selected cleanup action, and the site is located in a state where EPA implements the RCRA program. Thus the cleanup action is exempted from RCRA. This situation is explained in the description of the selected remedy chapter of the ROD.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
Toxic Substances Control Act (TSCA) 40 CFR 761	Regulates the storage, treatment and disposal of material contaminated with PCBs. Contaminated dredged sediment would generally follow the substantive requirements of 40 CFR 761.61, cleanup and disposal requirements for PCB remediation waste. Material meeting the definition of PCB remediation waste (761.3) would be disposed of using the three options under 761.61, which include a self-implementing option (761.61(a)), a performance-based option (761.61(b)), and a risk-based option (761.61(c)). Determination of whether there is a PCB remediation waste (as per 761.3) at the site may require determination of date of spill, PCB concentration of material spilled, or PCB concentration currently at site. If information is not available (e.g., date of spill), 761.61 may still be relevant and appropriate. The definition of PCB remediation waste, under 761.3, may include any concentration of PCBs. As such, 761.61 may be an ARAR for any concentration of PCBs. Selection of cleanup/disposal options under 761.61 for a Superfund site is made at the Regional level, in conjunction with the TSCA program. The risk-based option under 761.61(c) would be expected to be selected most often at Superfund sites.	Example 1. Although the source of PCBs is not known at this site, 761.61 may be relevant and appropriate. The risk-based option under 761.61 is selected. EPA's remedy is to dredge the contaminated sediments and send the dewatered sediments to a landfill, meeting the requirements for disposal of PCB remediation waste. Example 2. A PCB transformer is known to have broken open in the area of PCB-contaminated sediments prior to 1978, resulting in sediments, currently at the site, with PCB concentrations greater than 50 ppm. As this meets the 761.3 definition for PCB remediation waste, 761.61 may be applicable. A risk-based disposal plan is selected and is made part of the ROD.
Potential State and Tribal ARARs		
State Water Quality Standards Regulation	Under the CWA, states are required to designate surface water uses, and to develop water quality standards based on those uses and the AWQC. Often an applicable requirement. Where a tribe has promulgated water quality standards, these may also be an applicable requirement.	A tribe has an EPA approved water quality standard regulation which designated the uses of a river to include rearing of aquatic life and other uses. Design and construction of the selected remedy, including the confined aquatic disposal facility, needs to achieve the tribe's water quality standards based on that use.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
State Hazardous Waste Regulations	Many states have been authorized by EPA to implement the RCRA Subtitle C Hazardous Waste Program in lieu of EPA.	The sediment at a site was contaminated with a listed hazardous waste. The state has been authorized for RCRA, and decided to not adopt the hazardous waste identification rule (HWIR) sediment exemption. Treatment and disposal of the dredged contaminated sediment must meet or waive the state's hazardous waste regulations.
State Solid Waste Regulations	Most states have regulations for the location, design, construction, operation and closure of solid waste management facilities. Potential applicable or relevant and applicable requirement for disposal of non-hazardous waste contaminated sediment.	An alternative includes on-site upland disposal of dredged sediment. The feasibility study looks at the state solid waste regulations and determines that a disposal facility at two of the three possible sites can be designed to meet the ARAR. The third site is eliminated from further analysis.
Total Maximum Daily Load Regulation	Some states have established wasteload allocations in an EPA-approved and promulgated TMDLs. May be an applicable or a relevant and appropriate requirement, where such regulations exist, depending on whether the regulation specifically addresses the discharge. Non-promulgated TMDLs may be a TBC.	An alternative includes residual contamination that provides a small continuing load to the waterbody. EPA consulted with the state TMDL program to determine whether TMDLs are a potential ARAR or TBC and how they interact with an alternative that includes residual contaminants.
National Pollutant Discharge Elimination Permit regulations (NPDES)	Under the CWA, many states have been delegated the authority for the NPDES permit program. These regulations generally regulate discharges, including monitoring requirements and effluent discharge limitations for point sources. Where a remedy has a point discharge that is not regulated, the substantive requirements may be an applicable regulation.	A Superfund remedy includes dewatering of dredged contaminated sediments prior to disposal with discharge of the water to surface water. EPA consulted with the state NPDES permit program to determine water treatment standards prior the discharge.

receive without exceeding CWA water quality standards. TMDLs are established by the states, territories, or authorized tribes and approved by the EPA. Effluent limits in point source NPDES permits should be consistent with the assumptions and requirements in a wasteload allocation in an approved TMDL. The EPA established TMDLs are not promulgated as rules, are not enforceable, and, therefore, are not ARARs. TMDLs established by states, territories or authorized tribes may or may not be promulgated as rules. Therefore, TMDLs established by states, territories, or authorized tribes, should be evaluated on a regulation-specific and site-specific basis. Even if a TMDL is not an ARAR it may aid in setting protective cleanup levels and may appropriately be a TBC guidance. This should also be determined on a site-specific basis. In any case, project managers should work closely with regional EPA Office of Water and state personnel to coordinate matters relating to TMDLs. The project manager should remember that even when a TMDL or wasteload allocation is not enforceable the water quality standards on which they are based may be ARARs. TMDLs can also be useful in helping project managers evaluate the impacts of continuing sources, contaminant transport, and fate and effects. Similarly, Superfund's remedial investigation/feasibility study may provide useful information and analysis to the federal and state water programs charged with developing TMDLs.

Project managers should also be aware of Executive Orders such as those covered by the *Statement of Procedures on Floodplain Management and Wetland Protections*, 50 CFR Part 6, Appendix A. Although not ARARs, the Agency may follow Executive Orders as a matter of policy. The Statement of Procedures cited above sets forth EPA policy and guidance for carrying out Executive Orders 11990 and 11988. Executive Order 11988 concerns flood plain management and the evaluation by federal agencies of the potential effects of actions they may take in a flood plain to avoid, to the extent possible, adverse effects associated with direct and indirect development of a flood plain. Executive Order 11990 concerns protection of wetlands and the avoidance by federal agencies, to the extent possible, of the adverse impacts associated with the destruction or loss of wetlands if a practical alternative exists. OSWER Directive 9280.0-03, *Considering Wetlands at CERCLA Sites* (U.S. EPA 1994c), contains further guidance on addressing this Executive Order.

Examples of ways in which remedial strategies have been adapted in light of these Executive Orders as a matter of policy include the following:

- EPA determined that capping above grade would be an inappropriate alternative for remediating contaminated sediments in a small river, as the increased bottom elevation would increase the risk of flooding. Instead, the final EPA remedy called for dredging contaminated sediments and capping back to the existing grade; and

- When evaluating possible alignments for the access road to the contaminated sediment site, the region selected a route that avoided the wetland and that would minimize the potential for effects on the flood plain. During design of the access road, additional features were incorporated to further minimize any indirect impact on the flood plain.

3.4 ESTIMATING COST

Developing cost estimates is an essential part of evaluating alternatives. Guidance on preparing cost estimates and the general role of cost in remedial alternative selection is discussed in *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (U.S. EPA and USACE 2000).

The general elements of a cost estimate include the following:

- Capital costs;
- Operation and maintenance costs (O&M); and
- Net present value.

This cost estimate should not include potential claims for natural resource damages, but may include costs for mitigation of habitat lost or impaired by the remedial action, where appropriate.

3.4.1 Capital Costs

Capital costs are those expenditures that are needed to construct or install an alternative. Capital costs include only those expenditures that are initially incurred to implement a remedial alternative and major capital expenditures in future years. Capital cost elements that may be important at sediment sites include those listed in Highlight 3-3.

Highlight 3-3: Example Categories of Capital Costs for Sediment Cleanup

Categories	Capital Costs
General (may apply to several or all cleanup methods)	• Mobilization/demobilization • Site preparation (e.g., fencing, roads, utilities) • Construction monitoring, sampling, testing, and analysis before, during and immediately following construction (e.g., bathymetric surveys) • Environmental monitoring before, during, and immediately following construction (e.g., water quality monitoring) • Debris and/or structure (e.g., piers, pilings) removal and disposal • Project management and support throughout construction, including preparation of remedial action documentation and construction submittals • Post-construction habitat restoration (e.g., plantings) • Pilot studies • General contingency • Indirect costs • Implementation of institutional controls
Monitored Natural Recovery	• Monitoring and reporting prior to attainment of cleanup levels

Categories	Capital Costs
In-situ Capping	• Cap materials – Material costs – Equipment costs – Cost of mitigation if required under CWA §404 • Transport, storage, and placement of cap materials – Barge/tug lease costs – Stockpiling of cap material
Dredging or Excavation	• Dredging or excavation equipment costs • Engineering controls to protect water quality, such as silt curtains • Site decontamination for support facilities (e.g., truck wash, dewatering area) • Sediment isolation for excavation (e.g., sheetpile, earthen dams) • Construction of dewatering area/temporary storage of dredged material • Transporting sediment to treatment or disposal site – Barge/tug lease costs – Pipeline costs • Land acquisition costs for construction easements or relocating utilities
Pre-Treatment/Treatment	• Land acquisition costs • Construction of pre-treatment/treatment/storage buildings • Treatment of sediment • Treatment and discharge of water from dewatering process • Disposal of treatment residuals
In-Water Contained Aquatic Disposal, and In-Water or Upland Confined Disposal Facilities	• Land acquisition costs • Construction of disposal site – Demolition of existing facilities – Excavation to support berm • Berm construction – Imported materials for berm – Equipment costs • Capping disposal site – Cap materials – Equipment costs • Engineering controls to protect water quality • Cost of mitigation if required under CWA §404

Categories	Capital Costs
Upland Landfill Disposal	• Land acquisition costs • Construction costs • Transportation costs • Tipping fees for regional landfill

3.4.2 Operation and Maintenance Costs

Operation and maintenance costs are those post-construction/installation costs necessary to operate, maintain, or monitor the continued effectiveness of a remedy. These costs may be annual or periodic (e.g., once only, or once every five years). It is important to note that short-term O&M costs (e.g., operation of a sediment dewatering facility) are incurred as part of the Remedial Acton phase of a project, while long-term O&M costs (e.g., long-term monitoring after attainment of cleanup levels, or long-term cap maintenance) are part of the O&M phase of a project (U.S. EPA and USACE 2000). Some examples of O&M costs at sediment sites include the following:

- Operation of sediment or water treatment facilities;
- Maintenance of cap or disposal site;
- Maintenance of engineering site controls;
- Maintenance and monitoring of institutional controls;
- Long-term monitoring, sampling, testing, analysis, and reporting;
- Cost overrun contingency; and
- Project management and support.

3.4.3 Net Present Value

The NCP also provides that an analysis of remedy net present value, or present worth, should be used. A net present value analysis should be used to compare expenditures that occur over different time periods. This standard methodology allows for a cost comparison of different alternatives that have capital and operation, maintenance, and monitoring costs that would be incurred in different time periods on the basis of a single cost figure for each alternative. In general, the period of analysis should be equivalent to the project duration, resulting in a complete life cycle cost estimate for implementing the remedial alternative. Past EPA guidance recommended the general use of a 30-year period of analysis for estimating present value costs (U.S. EPA 1988a). While this may be appropriate in some circumstances, the blanket use of a 30-year period is not recommended. Site-specific justification should be provided for the period of analysis selected, especially when the project duration (i.e., time period required for design, construction, operation and maintenance, and closeout) exceeds the selected period of analysis (U.S. EPA and USACE 2000).

The discount rate that should be used for this analysis is established by the Office of Management and Budget (OMB). Based on NCP Preamble (55 FR 8722) and the OSWER Directive 9355.3-20, *Revisions to OMB Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis* (U.S. EPA 1993b), a seven percent discount rate should be used in estimating the present worth value for potential alternatives. This figure could be revised in the future, and project managers should use the current figure contained in an update of the OSWER Directive 9355.3-20. These rates may not be the same value that various potentially responsible parties (PRPs) or federal facilities use for similar analyses. For long-term projects (e.g., more than 30-years), it is recommended that the present value analysis also include a "no-discounting" scenario. The project manager should refer to *A Guide to Developing and Documenting Cost Estimates for the Feasibility Study* (U.S. EPA and USACE 2000) for more information.

The basis for a cost estimate may include a variety of sources, including cost curves, generic unit costs, vendor information, standard cost estimating guides, and similar estimates, as modified for the specific site. Because relevant site-specific cost data may not be available, costs estimates used early in the feasibility study frequently rely on historical data and parameters of similar past projects.

Substantial amounts of historical cost data for some components of sediment remediation, for example removal, transport, disposal, and residue management, may be available from other project managers. The project manager should refer to the ARCS program (U.S. EPA 1994b) for a discussion on the general elements of cost estimates for sediment sites. This document provides examples of percentages for general costs and site-specific costs for both in-situ and ex-situ remedies. In addition, many of the local district USACE offices have extensive experience with dredging and in-water construction and may be an additional source of good cost information.

3.5 INSTITUTIONAL CONTROLS

The term "institutional control" (IC) refers to non-engineering measures intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances by limiting land or resource use. ICs can be used at all stages of the cleanup process to reduce exposure to contamination. Chapter 7, Remedy Selection Considerations, offers guidance on when it may be appropriate to select a remedy that includes institutional controls at sediment sites and considerations regarding their effectiveness and enforceability. For more detailed information on ICs in general, refer to OSWER Directive 9355.0-74FS-P, *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (U.S. EPA 2000c) and Federal Facilities Restoration and Reuse Office (FFRRO) guidance, *Institutional Controls and Transfer of Real Property under CERCLA Section 120 (h)(3)(A), (B), or (C)* (U.S. EPA 2000d).

The following lists four general categories of ICs (U.S. EPA 2000c):

- Governmental controls;

- Proprietary controls;

- Enforcement and permit tools with IC components; and

- Information devices.

Usually, governmental controls (e.g., bans on harvesting fish or shellfish) are implemented and enforced by the state or local government. Proprietary controls, such as easements or covenants, involve legal instruments placed in the chain of title of the site or property. Enforcement tools include provisions of CERCLA Unilateral Administrative Orders (UAOs), Administrative Orders on Consent (AOCs), or Consent Decrees (CD). Information devices provide information or notification to the public, for example, non-enforceable fish consumption advisories.

Examples of three common types of ICs and informational devices at sediment sites include the following:

- Fish consumption advisories and commercial fishing bans;

- Waterway use restrictions; and

- Land use restriction/structure maintenance.

3.5.1 Fish Consumption Advisories and Fishing Bans

Fish consumption advisories are informational devices that are frequently selected as part of sediment site remedies. Commercial fishing bans are government controls which ban commercial fishing for specific species or sizes of fish or shellfish. Usually, state departments of health are the governmental entities that establishes these advisories and bans. Frequently, fish consumption advisories and fishing bans are already in place before a site is listed on the National Priorities List (NPL), but if not, it could be necessary for the state to issue or revise them in conjunction with an early or interim action, or the final remedial action. An advisory usually consists of informing the public that they should not consume fish from an area, or consume no more than a specified number of fish meals over a specific period of time from a particular area. Sensitive sub-populations or subsistence fishers may be subject to more stringent advisories. Advisories can be publicized through signs at popular fishing locations, pamphlets, or other educational outreach materials and programs.

3.5.2 Waterway Use Restrictions

For any alternative where subsurface contamination remains in place (e.g., capping, monitored natural recovery, or an in-water confined disposal site), waterway use restrictions may be necessary in order to ensure the integrity of the alternative. Examples include restricting boat traffic in an area to establish a no-wake zone, or prohibiting anchoring of vessels. In considering boating restrictions, it is important to determine who can enforce the restrictions, and under what authority and how effective such enforcement has been in the past. It may be necessary to evaluate remedial alternatives that involve changing the navigation status of a waterway. For a federally authorized navigation channel, deauthorization of the channel would be required. This can be a lengthy process that requires a formal request to the U.S. Army Corps of Engineers (USACE), an opportunity for users of the waterway to comment, and, ultimately, deauthorization by Congress. The state can have additional regulations to be followed to change harbor lines or the navigation status of a waterway. Lastly, a restriction on easements for installing utilities, such as fiber optic cables, can be important.

3.5.3 Land Use Restrictions/Structure Maintenance

Where contamination remains in place, it may be necessary for the project manager to work with private parties to implement use restrictions on nearshore areas and adjacent upland properties. For example, construction of boat ramps, retaining walls, or marina development can expose subsurface contamination and compromise the long-term effectiveness of the alternative. Ownership of aquatic lands varies by state and locality. In many cases, nearshore areas can be privately owned out to the end of piers. For private property owners, more traditional ICs, such as proprietary controls or enforcement tools with IC components, can be considered. Potentially, some of these restrictions can be implemented through agencies who permit construction activities in the aquatic environment. Several federal, state, and local laws place restrictions on and may require permits to be obtained for dredging, filling, or other construction activities in the aquatic environment. These include Section 404 of the Clean Water Act, 33 U.S.C. 1344, and Sections 9 and 10 of the Rivers and Harbors Act of 1899, 33 U.S.C. 401 and 403. It may also be possible to implement some ICs through coordination with existing permitting processes. Harbor Master Plans, state-designated port areas, and local authorities may also function to restrict certain uses.